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LIFE HISTORY OF THE ANGOUMOIS GRAIN MOTH IN MARYLAND

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INTRODUCTION

More than 500 articles on the Angoumois grain moth[3] have been published, but only a few of them report original information about the life history of the species. Réaumur (*7, p. 497*)[4] and Duhamel du Monceau and Tillet (*4*) in France, Candura (*3*) in Italy, and King (*6*) in Pennsylvania have been the chief sources upon which entomologists have depended for biological information. The work of the writers, begun in May, 1923, at the Sligo (Montgomery County), Md., laboratory of the Bureau of Entomology, was continued until the close of the summer of 1927. Four reports on certain phases of the work have been published (*5, 8, 9, 10*). In this bulletin the writers present their final reports on the work, with brief references to conclusions arrived at in their previous papers.

The laboratory work was conducted in a dwelling house used as a field laboratory and in an outdoor insectary. The sides and ends of the insectary were of wire netting over which, on the sides exposed to

[1] Died Aug. 23, 1932.
[2] The cooperation of G. W. Acorn, of Colesville, W. F. Garber, of Glenmont, and F. A. Blundon, of Silver Spring, Md., was most helpful and is gratefully acknowledged.
[3] *Sitotroga cerealella* Oliv.; order Lepidoptera, family Gelechiidae.
[4] Italic numbers in parenthesis refer to Literature Cited, p. 34.

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direct sunlight, there was a screen of cotton cloth. Land at the station and wheat fields and cornfields of several farmers were used for certain experiments. Except in the case of experiments with high and low temperatures and overwintering, the detailed life-history operations were conducted under room temperatures which rose and fell markedly, especially during the winter.

THE ANGOUMOIS GRAIN MOTH IN WHEAT AND CORN

The agriculture of the winter-wheat region east of the Appalachian Mountains, consisting typically of rotations of corn, wheat, and clover, provides an environment for the Angoumois grain moth that is probably more favorable than that of any other wheat-growing region in the United States. Even during years when climatic conditions do not favor outbreaks of the insect (*9*)—and such years are fortunately in the majority—the year-round food supply of corn and wheat, both in storage and ripening in the field, assures the diffuse perpetuation of the species. When weather conditions favorable to the insect occur, its reproductive powers are emphatically demonstrated, much to the concern of growers and millers of wheat. In the region which includes Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and North Carolina, wheat was harvested by approximately 345,000 farmers in 1919 (*2*). In Maryland alone about 26,300 wheat growers, comprising 54.8 per cent of all the farmers in the State (*2*), have been subjected to losses during years of unusual abundance of the species.

In the latitude of Maryland wheat is the only crop seriously affected by the Angoumois grain moth. Barley, rye, pop corn, and other seeds are sometimes infested, but losses in these grains are comparatively small. Damage to the large crop of field corn is unimportant; but the corn, being largely used on the farms where it is grown, is in storage on a considerable proportion of the farms throughout the year and serves as an important reservoir of infestation until the new wheat crop comes on.

ANNUAL CYCLE OF THE MOTH ON MARYLAND FARMS

The moth population reaches its height in the new wheat crop during the summer and early fall. Being an important cash crop, the wheat is to a large extent removed from the farms before the advent of cold weather, and only small, scattered supplies are left in the hands of growers. In the meantime, however, the ripening corn has become slightly but quite generally infested; and the insect passes the winter in the corn stored in bins, in scattering lots of held-over wheat, in waste wheat in straw, litter, and screenings, and to a small extent in barley, rye, and other seeds.

The moths can enter or leave at will the various types of buildings used for corn and wheat storage in Maryland. During the late fall, winter, and early spring moths are not in evidence, but they begin to emerge in May and fly to near-by fields of ripening wheat. At this season very little of the last year's wheat is left on the farms, and the corn supplies are diminished and frequently small. After the new crop of wheat is threshed and placed in storage following harvest in late June or early July, the moths attain their maximum abundance.

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Breeding is most rapid during the three months from June 15 to September 15, and is practically at a standstill from November 1 to May 15. Spring emergence begins about the middle of May in central Maryland. The adults of the first generation usually begin to emerge from new-crop wheat about the middle of July, but in favorable years some emergence may occur two or three weeks earlier, in which case it coincides with wheat harvest. The generations overlap and become mixed. Probably not more than three generations develop to their maximum numbers during a year in Maryland, but in exceptionally warm years the rate of development probably is increased to a point where there may be four generations.

EFFECTS OF SOME FARM PRACTICES ON MOTH INCREASE

In Maryland the usual method of harvesting wheat, following the operation of cutting and binding, consists of piling the bundles or sheaves into round shocks for curing. The shocked wheat is sometimes threshed in the field, but in most localities the sheaves, after drying for a time in the shock, are either stacked or piled in mows in barns or sheds for further curing. Although stacks are frequently made in the fields, the sheaves are more commonly taken to the farmyard (near stored grain and other moth sources) and are stacked there or placed in mows. Holding the grain in the straw to allow it to undergo a "sweat" or further ripening and drying process provides conditions favorable for moth increase. After the wheat is threshed it is either sold promptly or stored in bins which are ordinarily not suited for fumigation.

Wheat straw, always containing more or less waste wheat, is sometimes allowed to remain in the field where the threshing was done, with the result that wheat growing near by the following year becomes infested. Straw piles are often made in the feed yards, in order that the straw may be eaten by livestock and trampled into compost, or it is often baled for ease in handling or for sale. All such straw is a potential source of moths which may infest near-by ripening corn in the fall and growing wheat the following spring. However, as shown by the condition of samples taken from shocked wheat near old straw piles, straw that has been exposed during more than one winter is negligible as a source of moths.

OVERWINTERING OF THE INSECT

Of special interest and importance in a study of the activities of the Angoumois grain moth are the facts about the stages in which the insect passes the winter and the time of appearance of the first adults in the spring.

Detailed information about the life of the adults (p. 15) suggests that moths not given drinking water do not survive more than five weeks; that only a few, living under more favorable conditions, exceed that length of time; and that none live more than 52 days. No living adults are to be found during winter where outdoor temperatures prevail, and it may be concluded that the adult stage is not involved in the survival of the species during prolonged cold weather. Eggs were exposed at various times during the winter months, and did not overwinter successfully.

The relative importance of the larval and pupal stages in carrying the insect through the winter is shown by data in Table 1.

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TABLE 1.—*Stages of the Angoumois grain moth found in the spring of 1927 in wheat exposed during the winter to outdoor temperatures*

Date	Kernels dissected	Larvae						Pupae	
		One-fourth grown		One-half grown		Full grown			
		Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Mar. 7	50	0	0	0	0	8	1	0	0
Mar. 15	53	0	1	1	2	11	1	0	0
Mar. 22	50	1	3	5	6	10	6	1	0
Mar. 29	55	0	1	3	6	9	3	0	0
Apr. 5	50	0	0	6	10	12	8	0	0
Apr. 12	53	0	0	4	9	8	5	1	0
Apr. 18	53	0	3	1	7	12	2	0	1
Apr. 25	60	0	4	1	1	12	4	0	1
May 3	80	0	8	1	7	21	12	3	0
May 10	77	0	2	1	2	10	16	1	2
Total	581	1	22	23	50	113	58	6	4

From Table 1 it seems permissible to conclude that very few larvae that are less than half grown when cold weather stops their development in the fall are able to survive the winter. A mortality of 95.7 per cent of such larvae is shown in the foregoing table, with 68.5 per cent of the half-grown larvae, and 33.9 per cent of the full-grown larvae. The winter mortality among the 277 insects shown in Table 1 was about 48 per cent. King (*6*) stated that the insects pass the winter in Pennsylvania as one-half to full-grown larvae, an assertion that would seem to apply quite well to central Maryland where, in addition, a very few pupae and small larvae survive.

In Table 2 is given a summary of the temperatures recorded by the United States Weather Bureau (*11*) during the winter of 1926–27 at Takoma Park, Md., about 2 miles from the insectary in which the insects passed the winter.

TABLE 2.—*Summary of temperatures recorded at Takoma Park, Md., showing the mean, departure from normal, and minimum for each month from October, 1926, to April, 1927*

Month and year	Monthly mean	Departure of monthly mean from monthly normal	Monthly minimum	Month and year	Monthly mean	Departure of monthly mean from monthly normal	Monthly minimum
	°*F.*	°*F.*	°*F.*		°*F.*	°*F.*	°*F.*
October, 1926	55.6	−0.5	32	February, 1927	40.4	+8.2	27
November, 1926	43.3	−1.2	22	March, 1927	46.0	+2.9	14
December, 1926	32.0	−2.4	9	April, 1927	50.4	−2.6	31
January, 1927	32.2	−0:1	5				

In the insectary adults began to emerge from wheat exposed during the winter to outdoor temperatures on May 23, in 1925; on May 25, in 1926; and on May 10, in 1927. These dates of the beginning of spring activity are of much interest in connection with the following discussions of springtime dispersion of the moths to growing wheat and of the liberation of young larvae on wheat plants.

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SPRING DISPERSAL TO GROWING WHEAT

The dispersion of the Angoumois grain moth to wheat fields has been considered by the writers in a previous publication (*10*), from which Table 3 has been taken.

TABLE 3.—*Summary of location, size of samples, and degree of infestation of shocked wheat by the Angoumois grain moth, 1924, 1925, and 1926*

Year	Sample No.	Average number of kernels in samples	Average distance from probable sources of moths	Average infestation	Year	Sample No.	Average number of kernels in samples	Average distance from probable sources of moths	Average infestation
			Feet	*Per cent*				*Feet*	*Per cent*
1924	1	11,069	173	0.40	1926	1	12,897	140	0.07
	2	12,423	360	.11		2	13,180	250	.04
	3	11,540	780	.03		3	13,810	372	.02
1925	1	13,584	189	.04					
	2	14,372	338	.02					
	3	15,100	485	.01					

The following excerpts from the report on dispersion (*10*) will serve to explain the method used in the surveys summarized in Table 3.

Data obtained in 1924, 1925, and 1926 are here summarized and discussed. These are based on inspections of the conditions on different farms and on the infestations found in samples of wheat heads collected at harvest time in the field. Since it is impossible to take samples through the center of a wheat field before the grain is cut without trampling a considerable quantity of it, samples were taken from shocks, and visits to farms were begun as soon as harvesting operations started. Farms were inspected upon which shocked wheat was present within a few hundred feet of the farm buildings. Each sample consisted of three 6-pound paper bags of wheat heads, the bags being filled about three-quarters full. On each farm a sample, designated as No. 1, was taken from two or three shocks which were located nearest to the farm buildings or to other probable sources of moths. In most cases a second sample was taken at a greater distance from the moth sources; a third sample was taken from shocks still farther away, usually in line with the shocks from which samples No. 1 and No. 2 had been obtained. In choosing the area to be sampled, the desirability of avoiding the parts of a field in the vicinity of possible moth sources on neighboring farms was recognized.

Before the wheat was sampled in the field the owner's experiences with the moth were noted so far as possible, and, with a few exceptions, any grain in storage on the place was examined for infestation. A rough map was made of each farm, showing its location, the location of different kinds of stored grain, and the approximate direction and estimated distance of the sampled shocks from possible sources of moths. The apparent condition of the stored grain with respect to moth infestation and moth parasites was also recorded. Any litter remaining on the sites of mows where wheat had been piled before threshing was examined, and in 1925 and 1926 the presence of loose and baled wheat straw was noted.

In 1924 the inspections were made in west-central Maryland, mainly in Montgomery County. Much of the same area was gone over in 1925, and samples were also taken in southern Maryland (St. Mary's County), in the Shenandoah Valley in Virginia, in southeastern Pennsylvania, and on one farm in Delaware. In 1926 farms were inspected and samples were taken on the Eastern Shore of Maryland, in central and northern Maryland, and in southeastern Pennsylvania. The material collected was kept for observation in an outdoor insectary.

The conclusions indicated by the surveys were as follows:

(1) The principal moth sources which cause preharvest infestation of wheat in the eastern wheat region are ear corn and wheat in straw, bins, and litter from mows; (2) field infestation of the wheat crop in fields near sources of moths is the rule rather than the exception, and the percentage of infestation decreases as the distance from moth sources increases; (3) the percentage of infestation in

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the field is low, but an infestation of 0.26 per cent indicates a moth population of about 28,500 [5] per acre (owing to the rapidity of increase of the Angoumois grain moth, these early infestations develop into destructive outbreaks when weather conditions are favorable); (4) if preharvest infestations were eliminated, the severe and widespread damage now caused by the insect would be a thing of the past.

A survey supplementary to those made in 1924, 1925, and 1926 was carried out on farms in Maryland and Virginia in 1927. Following this survey the percentage of infestation in the shocked wheat was not estimated, but the condition of the single sample taken on each farm from shocks near probable moth sources was observed. The results of the examination of moth sources and of samples collected are summarized in Table 4.

TABLE 4.—*Dispersion of the Angoumois grain moth to wheat fields, as indicated by the condition of samples of wheat heads taken from shocks in Maryland and Virginia, 1927*

Farm No.	Date of farm inspection and sampling	Probable sources of moths	Estimated distance of sampled shocks from probable source of moths	Condition of sample
			Feet	
1	June 29	Corn, straw	300	Not infested.
2	June 30	Straw	150	Slightly infested.
3	do	Corn, straw	50	Do.
4	July 5	Corn	325	Do.
5	do	do	200	Infested.
6	July 6	Corn, barley, rye, straw	25	Slightly infested.
7	do	Straw	20	Do.
8	do	Corn, wheat, straw	25	Do.
9	July 8	Screenings, straw	40	Infested.
10	do	Corn	350	Slightly infested.
11	July 9	Corn, straw	700	Do.
12	July 12	Wheat, straw	400	Not infested.
13	do	Straw	75	Do.
14	do	Corn, straw	700	Slightly infested.
15	do	do	30	Not infested.
16	do	do	20	Do.
17	July 13	Straw	40	Slightly infested.
18	do	Wheat, corn	40	Not infested.
19	July 16	Corn	300	Do.
20	do	Wheat, corn	400	Slightly infested.
21	do	Straw	100	Do.
22	July 18	Screenings, straw	50	Infested.
23	do	Corn, straw	45	Heavily infested.
24	do	Corn	300	Not infested.
25	do	do	30	Heavily infested.
26	do	Wheat, corn, straw	200	Slightly infested.
27	do	Straw	300	Do.
28	do	Corn, straw	200	Do.
29	July 20	Straw	40	Do.
30	do	do	300	Infested.
31	do	Corn	400	Not infested.
32	do	None		Do.
33	July 22	do		Do.

The conclusions indicated by the previous surveys, quoted above, are supported further by the data in Table 4. Infestation was present in ripe wheat on 22 of the 33 farms visited. The samples from 16 farms were recorded as "slightly infested," from 4 farms as "infested," and from 2 farms as "heavily infested." Probable sources of moths were present on 31 of the farms, old-crop wheat was in storage on only 5 farms, corn on 19, and straw on 22.

[5] Later investigations indicate that the number would be from 32,000 to 35,000 per acre.

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The importance of loose and baled straw as a widely distributed source of moths is indicated by the findings just recorded, since the waste wheat remaining in straw was the only apparent source of the insects on eight farms, on seven of which the wheat in near-by fields was infested at harvest time. In order to secure definite information about the quantity of waste wheat that is present in straw the writers secured two bales from a wheat grower; one bale contained very little chaff and the other more than the average quantity of chaff. The bale that was mostly straw contained 93 kernels of wheat, while the chaffy bale included 4,050 kernels. Therefore if a farmer holds for the winter 100 or 200 bales of straw or an equivalent amount of loose straw he has, in the straw alone, a probable source of sufficient moths to start infestation in his ripening corn in the fall (see farms Nos. 2, 3, and 4, Table 6); and the wheat kernels in the straw serve as breeding material for an overwintering generation of the insects which may, as indicated in Table 3, infest his wheat crop the following year. It is true that straw in whole bales is so tightly compressed that only moths which emerge from kernels near the outside of the bales could escape, but as a matter of fact piles of baled straw ordinarily include also broken bales and much other loose material.

LIBERATION OF NEWLY HATCHED LARVAE ON GROWING WHEAT

The importance of preharvest infestation of wheat, upon which depends the ability of the Angoumois grain moth to reach destructive numbers, led to the question, At what stages of ripeness of the wheat kernel can a young larva establish itself upon it?

Three methods of securing the desired information were considered: (1) Liberating adults within cloth bags tied over the heads of growing wheat, (2) placing freshly laid eggs upon the heads, or (3) liberating newly hatched larvae upon growing wheat. Because it gave promise of allowing a more accurate control of the time of infestation and of the numbers of young larvae present upon the wheat, the last procedure was followed.

With some minor departures early in the work the following method was employed at intervals along the edge of a wheat field: A handful of heads of green wheat was tied together with raffia, the bunch tied to a stake to prevent breaking by wind, and the whole covered by a tarlatan bag, as shown in Figure 1. The bags were used to reduce the possibility of natural infestation of the wheat, both before and after artificial infestation. That the tarlatan bags protected developing wheat heads from natural infestation was demonstrated by experiment.

On consecutive days, weather permitting, a known number of newly hatched larvae were taken to the field in veterinary capsules, the bags were removed from several bunches of wheat heads, and a capsule with top removed was inverted over a single wheat head in each bunch. On wheat heads still encased in the sheath leaves, liberations were made both with and without slitting the sheath leaves with a knife. When the larvae had crawled from the capsule into the wheat the capsule was removed, the tarlatan bag replaced, and the bunch of plants was labelled.

Just before the wheat in the field was harvested the bunches of ripe wheat plants, still protected by the bags, were cut off near the ground.

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Samples of wheat heads were also taken near the line of bagged heads, one sample being taken near the wheat upon which each daily liberation of larvae had been made. The emergence of moths from these controls is believed to be a reasonably accurate index of the natural infestation in the field. The wheat heads, protected by paper bags, were allowed to dry in the insectary for about 10 days, when the kernels were shelled off and placed in vials to facilitate the daily recording of emergence.

During the course of the liberations a record of general weather conditions was kept for the reason that such phenomena as cold rains and high winds would be expected to influence the ability of the insects to establish themselves on the wheat.

The stages of ripeness listed in Table 5 indicate the prevailing conditions in the wheat fields over three years. The grain passes un-

FIGURE 1.—Experiment in the liberation of newly hatched larvae of the Angoumois grain moth to determine the stages of ripeness at which the insect can become established on the wheat

evenly and imperceptibly from one stage to the next. Even before the plant blossoms, a rudimentary kernel is already formed. Development is rapid, the green kernel being filled with a watery sap. The milk stage is reached when the kernels are plump and light green, at which period a milky juice spurts out when a kernel is crushed. Kernels in the soft-dough stage are characterized by a very faint greenish color, fading to buff, the kernels being easily crushed and broken but without free juice. Wheat in the hard-dough stage may be flattened by pressure of the fingers, but the kernels do not break open. Firmness increases until the grain can not be cut through with the thumb-nail, at which time the grain is usually harvested although experiments have demonstrated that wheat in the hard-dough stage may be harvested without loss of yield.

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TABLE 5.—*Results of experiments to determine the stages of ripeness at which standing wheat may become infested with larvae of the Angoumois grain moth*

Date	Prevailing stage of ripeness of wheat	Liberations of larvae	Total larvae liberated	Adults which emerged from— Experimental wheat	Adults which emerged from— Control wheat	Larvae in experimental wheat which produced adults	Weather conditions on date of liberation
		Number	*Number*	*Number*	*Number*	*Per cent*	
1924							
June 24	Milk	5	239	22	0	9.2	Hot, trace of rain.
25	do	4	179	13	3	7.3	Fair, hot, fresh breeze in forenoon; thunderstorm p. m.
26	do	7	465	19	0	4.1	Fair and cool.
27	do	3	152	4	0	2.6	Hard rain in forenoon, shower in afternoon.
28	do	5	261	8	3	3.1	Cool and cloudy.
29	do	5	284	11	0	3.9	Hot, partly cloudy, light breeze.
30	Soft dough	7	699	48	1	6.9	Fair and warm.
July 1	do	5	369	27	0	7.3	Moderate temperatures, cloudy.
2	do	6	411	11	0	2.7	Moderate temperatures, partly cloudy.
3	do	7	543	37	0	6.8	Do.
4	Hard dough	6	526	51	0	9.7	Do.
5	do	7	725	48	0	6.6	Do.
6	do	7	947	60	0	6.3	Do.
7	do	8	1,054	51	0	4.8	Moderate temperatures, showers, fresh breeze.
8	do	7	700	61	0	8.7	Warm, cloudy, heavy showers.
	Total	89	7,554	471	7	6.2	
1925							
May 27	Blossom	3	105	23	1	21.9	Fair and warm, gentle breeze.
28	do	3	222	18	3	8.1	Do.
29	do	5	406	33	1	8.1	Warm, thunderstorm 2 p. m.
30	do	5	427	31	2	7.3	Fair and warm, gentle breeze.
31	do	5	595	43	0	7.2	Fair and warm.
June 1	Milk	5	481	43	0	8.9	Fair and hot.
2	do	5	505	49	0	9.7	Do.
3	do	5	781	43	0	5.5	Do.
4	do	5	800	6	0	0.7	Do.
5	do	5	927	27	0	2.9	Do.
6	do	5	527	23	0	4.4	Do.
7	do	3	359	20	1	5.6	Do.
8	do	3	244	14	1	5.7	Do.
	Total	57	6,379	373	9	5.8	
1926							
May 20	Prebloom, no visible heads.	5	432	2	0	0.5	Fair and warm, light breeze.
21	do	5	430	1	0	.2	Do.
22	do	5	354	2	0	.6	Fair and warm, shower in afternoon.
24	do	5	326	5	0	1.5	Fair and cool.
25	do	4	212	0	9	0	Do.
26	Prebloom, heads appearing.	4	162	2	9	1.2	Fair and warm.
27	Prebloom, heads numerous.	3	130	0	1	0	Do.
28	do	5	435	5	0	1.1	Fair and cool.
29	A few heads in bloom	4	216	2	0	.9	Fair and warm.
30	Most plants headed	3	218	3	0	1.4	Do.
31	More plants in bloom	4	249	7	0	2.8	Do.

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TABLE 5.—*Results of experiments to determine the stages of ripeness at which standing wheat may become infested with larvae of the Angoumois grain moth*—Continued.

1926

Date	Prevailing stage of ripeness of wheat	Liberations of larvae	Total larvae liberated	Adults which emerged from— Experimental wheat	Adults which emerged from— Control wheat	Larvae in experimental wheat which produced adults	Weather conditions on date of liberation
		Number	*Number*	*Number*	*Number*	*Per cent*	
June 1	Bloom general	4	166	0	4	0	Warm, heavy wind and rain.
2	do	2	100	1	0	1.0	Fair and warm.
3	do	2	176	7	0	4.0	Do.
8	do	3	303	2	0	.7	Fair and warm, fresh breeze.
9	Milk stage	4	598	24	1	4.0	Fair and warm.
10	do	3	688	7	1	1.0	Fair and warm, fresh breeze.
	Total	65	5,195	70	25	1.3	

1927

Date	Prevailing stage of ripeness of wheat	Liberations of larvae	Total larvae liberated	Adults which emerged from— Experimental wheat	Adults which emerged from— Control wheat	Larvae in experimental wheat which produced adults	Weather conditions on date of liberation
May 30	Prebloom, 60 per cent in head.	3	170	6	0	3.5	Cool and cloudy.
31	do	3	202	7	0	3.5	Warm and cloudy.
June 1	A few heads in bloom	5	461	15	0	3.3	Cool and fair, high wind.
2	80 per cent in head, more heads in bloom.	6	535	40	0	7.5	Warm, no breeze.
3	90 per cent in head, 40 per cent in bloom.	6	746	37	0	5.0	Cool and cloudy.
4	do	5	662	51	0	7.7	Cool and rainy.
5	Most plants headed	5	669	54	0	8.1	Warm in morning, cool and windy in afternoon.
6	50 per cent in bloom, 100 per cent in head.	6	639	46	0	7.2	Fair and warm.
7	do	5	641	31	0	4.8	Cool, heavy clouds.
8	60 per cent in bloom	5	725	55	0	7.6	Warm, light breeze.
9	Bloom general	4	400	39	0	9.7	Hot.
10	Kernel contents watery	4	462	26	2	5.6	Do.
11	do	6	475	60	0	12.6	Hot, high winds.
12	do	5	701	67	0	9.6	Hot, strong breeze.
13	Milk stage	4	217	28	0	12.9	Fair and warm.
15	do	5	480	21	0	4.4	Warm, slightly cloudy.
16	do	5	552	34	2	6.2	Warm, partly cloudy.
17	do	3	232	21	0	9.1	Warm.
18	do	2	154	13	0	8.4	Cool; low, heavy clouds, strong breeze.
19	do	1	49	4	0	8.2	Fairly warm, showers.
20	Soft dough	3	159	14	0	8.8	Cool and rainy.
21	do	3	134	16	0	11.9	Hot, partly cloudy.
22	do	6	524	62	4	11.8	Hot, occasional showers.
23	do	3	183	11	1	6.0	Hot, partly cloudy.
24	do	2	146	3	5	2.1	Cloudy in the morning; hot, partly cloudy, in afternoon.
25	do	1	46	3	(?)	6.5	Hot, a few clouds, strong breeze.
26	do	2	154	16	4	10.4	Hot in forenoon; cool in afternoon.
27	Hard dough	3	244	13	0	5.3	Cool, partly cloudy.
	Total	111	10,762	793	18	7.4	

The results shown in 1926 and 1927 indicate that newly hatched larvae are able to establish themselves on wheat even before the heads have pushed out of the enveloping sheath leaves and at least a week before bloom appears.[6] King (*6*), working in Pennsylvania, had

[6] The small size of the newly hatched larvae probably enables them to find their way easily to the ensheathed wheat head, and their ability to burrow into mature wheat would enable them to gnaw through the soft, green bracts. The investigation was brought to a close before the question was answered as to what the larvae feed upon at this early stage in the development of the wheat kernel.

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already come to the conclusion that infestation could occur as early as when wheat is in the milk stage.

The facts referring to the dates of spring emergence, brought out in the discussion of overwintering, and the foregoing liberation experiments serve to explain the widespread infestation of growing wheat shown in the reports on dispersion to wheat fields. (Tables 3 and 4.) The first moths of the season emerge in May, several weeks earlier than wheat harvest. Their offspring are able, however, to subsist on the wheat plant as soon as, or even before, the heads appear. But, judging from the results of liberations of young larvae on growing wheat, the percentage of survival is small, and this perhaps helps to account for the low percentages of wheat kernels found to be infested in the field at harvest time. Of the 29,890 larvae liberated during the four seasons' work, only 1,707, or 5.7 per cent, attained the adult stage, a small result when compared with the 75.7 per cent recorded in Table 15. In 1924 the shortest period from liberation of larvae to emergence of the first adults ranged from 42 to 32 days for the liberations made in June, and was almost uniformly 31 days for those made during the first week of July. The percentage of larvae which completed development during the 1926 work (1.3) was considerably less than the quite uniform averages of the other three years, when the percentages were 6.2, 5.8, and 7.4.

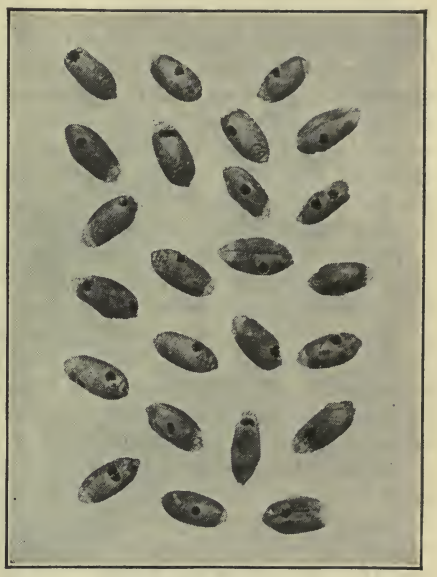

FIGURE 2.—Wheat kernels showing exit holes of the Angoumois grain moth. ×1⅓. (Back)

Perhaps the most useful point brought out by the experiments summarized in Table 5 is that any clean-up operations which growers may practice should not be delayed until the time of wheat harvest, but should be completed before the wheat is headed, and preferably before May 1.

THE ANGOUMOIS GRAIN MOTH IN SEED WHEAT

It is generally recognized that a real but intangible loss results when wheat infested by the Angoumois grain moth is used for planting. This insect usually destroys all or part of the germ and at least half of the endosperm during its larval feeding, and seeds so injured either produce week seedlings or do not germinate at all. A single moth developing in each of 1,000 kernels of wheat results in a loss of about 56 per cent of the weight of the grain (*1*). Such grain is illustrated in Figure 2.

Another aspect of the results of planting wheat so infested was considered many years ago in France by several investigators, including Duhamel du Monceau and Tillet (*4*), who concluded that moths were able to escape from the soil after they had emerged from planted

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wheat. The possibility that wheat planted in Maryland in October might carry the insect through the winter with consequent field infestations of growing wheat the following May seemed to justify an investigation.

In the fall of 1924 and again in 1925 well-infested wheat was planted thickly in small plots at various depths, and in the fall of 1926 similar plantings were made in large flowerpots sunk in the soil with their tops even with the surface, the grain in half the pots being covered with garden loam and in the other half with sand. The experimental plots and flowerpots were covered with cheesecloth or tarlatan cages the spring following the planting. No moths were observed in any of the cages although they were examined frequently.

The contents of 20 of the flowerpots planted outdoors in November, 1926, were sifted in May, 1927, but no living insects were found. No moths emerged from the wheat which was recovered during the sifting.

Since no survival of Angoumois grain moths was apparent during the spring from any of the planted wheat the appropriate conclusion is that the planted kernels either sprout in the fall or decay during winter and spring, in either case exposing the insects within to conditions which they are unable to endure. If any do survive, the compacted soil prevents their escape as adults. Similar experiments conducted by King (*6*) indicated no survival in planted wheat.

Further information about the fate of the insects when the kernels they inhabit are planted was obtained by planting infested grain at different depths indoors in battery jars in October, 1926. Emergence of 19 moths was observed early in November from wheat planted under 1 inch of sand, which number was about 7 per cent of the expectancy of 269, the latter figure being obtained from records of emergence from unplanted control wheat. No moths escaped from wheat planted indoors under 1½ and 2 inches of moist sand.

In late November and early December one-half the depth of the superimposed sand was taken from each jar with the result that 5 living full-grown larvae and 4 inhabited cocoons were found. Sifting the remaining sand, mixed with sprouted and decayed kernels, yielded the following living forms: 2 adults, 4 naked pupae, 4 half-grown larvae, and 4 full-grown larvae; 1 pupa and 3 full-grown larvae were dead; 3 empty cocoons and 4 inhabited cocoons were found. An unexpected tendency of the larvae to leave the planted kernels was established, and cocoons constructed in the soil (fig. 3) were observed for the first time.

DISPERSAL TO CORNFIELDS

The losses due to infestation of field corn by the Angoumois grain moth, although important farther south, are of little direct consequence in Maryland. As already mentioned, however, infestation in corn is indirectly an important matter, as this grain, widely distributed on farms throughout the year, constitutes a perennial reservoir of moths which, in the spring and early summer, fly to and infest near-by wheat fields.

In an attempt to determine the extent and degree of field infestations of ripening corn the writers made a survey of a few farms late

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in November, 1926, when the husking of shocked corn was general in central Maryland. The method used was similar to that applied to the surveys of wheat-field infestation in 1924, 1925, and 1926; the farm premises were examined for probable sources of moths, and samples of grain were taken from shocks at three distances from such sources. Since ears of corn are usually well covered by husks, only the tips of partly unprotected ears were gathered, each sample comprising about one-third bushel of such tips.

Following a winter's exposure to outdoor temperatures in the insectary, the tips were shelled (May 12 and 13, 1927), and the

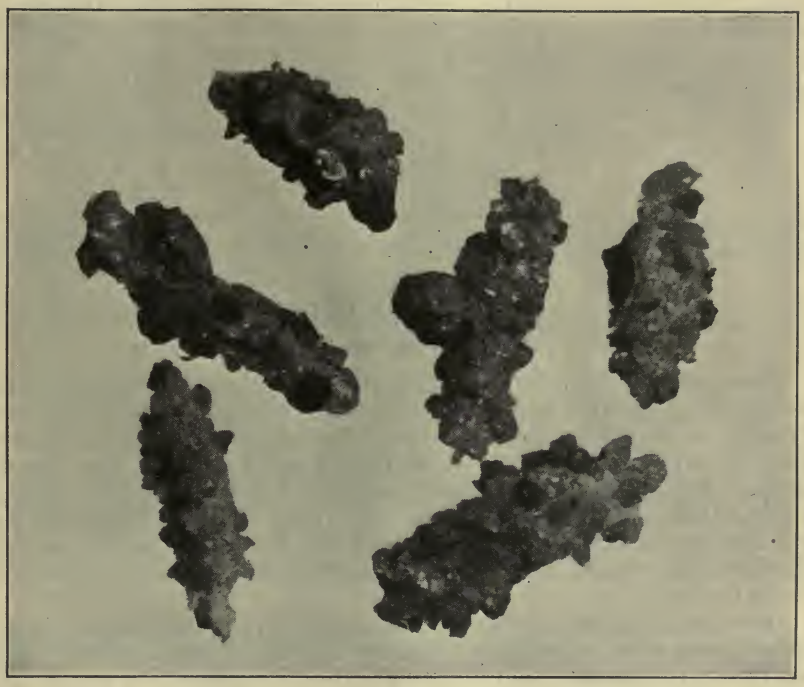

FIGURE 3.—Cocoons constructed by larvae of the Angoumois grain moth which escaped from planted wheat and pupated in the soil. ×5

shelled corn was placed to a depth of about 2 inches in cheesecloth-covered jars. Table 6 shows the condition of the samples as indicated by the emergence of adults.

The information given in Table 6 shows that the Angoumois grain moth infested corn on five out of six farms taken at random in central Maryland in a year when the insect was not plentiful. The insects which survived the winter in the corn and which emerged as moths in May and June, 1927, doubtless contributed to the infestation of the growing wheat on thousands of Maryland farms.

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TABLE 6.—*Dispersal of the Angoumois grain moth to cornfields as indicated by the condition of samples of ear corn taken at husking time, 1926*

Farm No.	Date of farm inspection and sampling	Sample No.	Probable sources of moths	Estimated distance of sampled shocks from probable sources of moths	Condition of sample as shown by examinations in the spring and summer of 1927
				Feet	
1	Nov. 23	1	Wheat, old corn	300	Slightly infested.
		2	do	450	Do.
		3	do	550	Not infested.
2	do	1	Straw	100	Slightly infested.
		2	do	200	Not infested.
		3	do	300	Do.
3	Nov. 24	1	do	500	Slightly infested.
		2	do	1,000	Not infested.
		3	do	1,100	Do.
4	do	1	do	300	Slightly infested.
		2	do	400	Not infested.
		3	do	500	Slightly infested.
5	do	1	Wheat, corn, straw	300	Not infested.
		2	do	400	Do.
		3	do	500	Do.
6	Nov. 29	1	Barley, straw	150	Slightly infested.
		2	do	225	Not infested.
		3	do	300	Slightly infested.

LIFE-HISTORY DETAILS

BEHAVIOR OF THE ADULTS

The shining, golden-buff insect is able to squirm its way among the kernels of wheat and to escape to the surface from a depth of at least 4 inches, as shown by tests in which infested wheat in glass cylinders was covered with uninfested wheat from 2 to 9½ inches deep. Adults escaped through 4 inches of wheat and moved upward 3 inches through wheat 6 inches deep. In the small interstices of bulk wheat the wings and legs are of little use; progress is made by vermiculation or peristaltic movements of the abdomen, followed immediately by pulsations of the thorax.

After reaching the surface of the wheat, or, in the case of exposed grains, soon after emergence from the cocoon, which is often pulled partly out of the exit hole by the efforts of the insect to escape, the adult occupies itself in getting its wings into working order. The abdomen is pointed downward out of the way, and the wings are held in a nearly perpendicular position, close together over the body. The wings are frequently lowered and raised again during the drying process. The posterior pair of legs is held up along the sides of the abdomen. Having dried and become smooth and rigid, the wings are lowered to a horizontal position, finally assuming the normal posture in which they cover the abdomen in the manner of a gable roof.

When adults are frightened they frequently lie on their backs and progress with very rapid skittering movements, sliding along by quick pushing strokes given by the extremities of the mesothoracic and metathoracic legs. Flight is strong but erratic and not long sustained; the insects remain at rest a large part of the time. Short, skipping flights are frequent. Some individuals when disturbed seek shelter in dark places, whereas others fly to the light.

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Males are evidently attracted by the odor of the females, since males have been observed dancing or pirouetting upon the cheesecloth covers of jars in which inaccessible females were confined. The same dance is usually begun immediately after a male is placed in a vial with a female.

Observations were made on the duration of mating of 22 newly emerged pairs between August 26 and September 12, 1923. One pair remained together for but 15 minutes, 13 pairs for from 1 to 2 hours, 5 pairs for 2 to 3 hours, and 3 pairs for more than 3 hours. The longest period was 3 hours and 20 minutes.

Mating takes place more than once in the case of moths confined by pairs in vials. A female was seen mating after having deposited 83 eggs; another after she had laid 97 eggs, and another mated after having laid 281 eggs. A temperature of about 70° F. seems to be most favorable for the mating of moths in confinement. Mating activities are reduced at temperatures above 80°.

LONGEVITY OF ADULTS

Table 7 gives a summary of longevity records of mated Angoumois grain moths made during a period of 21 months, from December, 1923, to the fall of 1925.

TABLE 7.—*Summary of records showing longevity of mated Angoumois grain moths exposed to contrasting moisture conditions, 1923 to 1925*

Longevity (*days*)	Number of moths included in class covered by longevity range						Longevity (*days*)	Number of moths included in class covered by longevity range					
	Under normal conditions		Under high humidity		Drinking water supplied			Under normal conditions		Under high humidity		Drinking water supplied	
	Males	Females	Males	Females	Males	Females		Males	Females	Males	Females	Males	Females
1–5	40	43	21	19	14	19	31–35	-------	-------	-------	1	2	4
6–10	133	128	65	55	71	59	36–40	-------	-------	-------	-------	-------	5
11–15	20	26	80	80	74	77	41–45	-------	-------	-------	-------	-------	2
16–20	-------	1	14	30	47	40	46–50	-------	-------	-------	-------	-------	2
21–25	-------	1	2	7	16	26	51–55	-------	-------	-------	-------	-------	1
26–30	-------	-------	-------	1	5	12							
							Total	193	199	182	193	229	247

The effect of drinking water in prolonging the life of adults is demonstrated in Table 7. The water was supplied in very small vials, placed inside the life-history vials and closed with a loosely fitting cotton plug which was pulled by capillarity toward the bottom of the vial as the water decreased in quantity, the cotton remaining wet as long as there was any water left. Moths took the water eagerly through their uncoiled probosces. For others a condition of high humidity was secured by placing life-history vials, provided with perforated covers, in a closed container kept humid by an ample water surface.

The longest life recorded in this series was 51 days, beginning December 9, 1924, although (see p. 30) one female lived for 52 days at a controlled temperature range of 60.8° to 64.4° F.

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OVIPOSITION

PREOVIPOSITION, OVIPOSITION, AND POSTOVIPOSITION PERIODS

A summary of the duration of the preoviposition, oviposition, and postoviposition periods of female moths observed from December, 1923, to the fall of 1925 is given in Table 8.

TABLE 8.—*Preoviposition, oviposition, and postoviposition periods of mated female Angoumois grain moths exposed in parallel series to contrasting moisture conditions 1923 to 1925*

Duration (*days*)	Numbers of moths included in class covered by duration period								
	Preoviposition period			Oviposition period			Postoviposition period		
	Under normal conditions	Under high humidity	Drinking water supplied	Under normal conditions	Under high humidity	Drinking water supplied	Under normal conditions	Under high humidity	Drinking water supplied
0	17	20	23				6	8	32
1–3	93	88	110	75	47	40	107	86	133
4–6	25	29	46	57	56	39	23	34	30
7–9	2	17	25	5	38	50	1	20	9
10–12	1	2	5	1	12	46	2	7	2
13–15	0		2	1	2	17		0	3
16–18	0		1		1	13		0	4
19–21	1		0			4		0	1
22–24			1			3		1	1
Over 24			3			4			1
Total	139	156	216	139	156	216	139	156	216

Only females that laid eggs are included in Table 8. In cases where a moth laid eggs during the first or last day of her life, such a day is counted in the oviposition period and the preoviposition or postoviposition period is recorded as zero.

OVIPOSITION RECORDS

For securing oviposition records in the laboratory the writers used two pieces of dark cardboard (*5*) fastened together with a paper clip and so shaped as to fit the life-history vial loosely and to permit removal and introduction of the cardboard without injuring the insects. The vials were closed with pill-box covers, blackened on the inside to produce a color contrast with any eggs which might be deposited on them. The smooth surface of the covers was not attractive (as were cotton plugs) to ovipositing moths. Nearly all eggs were laid in the crevice between the cardboard strips, to which they became loosely attached when their surface dried.

When newly laid, the eggs are pearly white, and they remain so if they are infertile; but fertile eggs assume a bright red color, usually within 24 hours. Figures 4 and 5 illustrate the appearance of eggs laid on growing wheat and on mature field corn. The eggs are deeply fluted longitudinally, the grooves being especially pronounced at the smaller or anterior end.

The oviposition records of the females referred to in Table 8, together with 128 others that deposited no eggs, are summarized in Table 9, in which the usefulness of drinking water to the females is strikingly shown. Those which were kept under normal conditions deposited 8,051 eggs, an average of 40.5; the females in a humid

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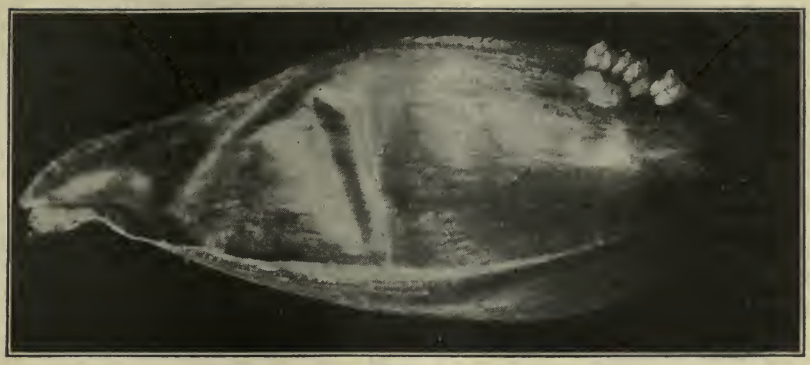

FIGURE 4.—Eggs of the Angoumois grain moth deposited on the chaff of a kernel of ripening wheat, between the palea and the remaining florets of the spikelet. × 10

FIGURE 5.—Eggs of the Angoumois grain moth deposited beneath the membrane near the tip of a kernel of field corn. × 10

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atmosphere laid 9,841 eggs, an average of 51; and the insects which were given drinking water produced 20,680 eggs, averaging 83.7 eggs each. High humidity effected an increase of about 26 per cent over the fecundity which obtained under normal conditions, whereas an increase of about 107 per cent may be credited to drinking water. The greatest number of eggs deposited by one female was 389. Unmated females do not deposit eggs. As a rule the moths which develop in corn are larger than those from wheat and are also more prolific.

The relation of drinking water to fecundity is least evident during July, August, and September, when the moths normally are the most prolific, as indicated in Figure 6. Figure 6 shows also, as does Table 7, the tendency of females to live longer than the males.

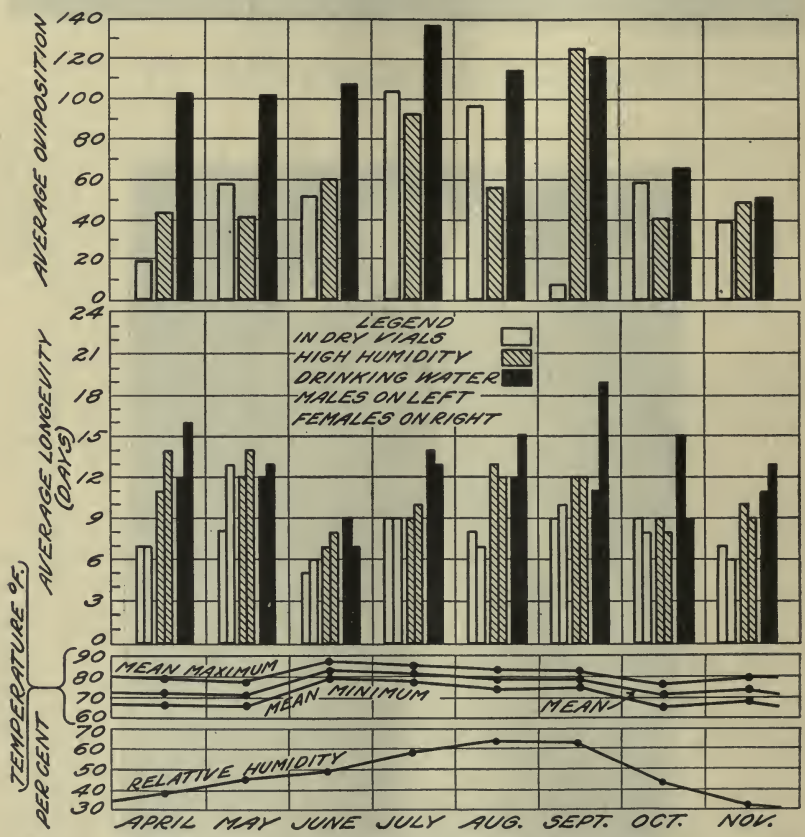

FIGURE 6.—The fecundity and longevity of mated pairs of Angoumois grain moths exposed to contrasting conditions in 1925

Females ordinarily deposit eggs most profusely during the first two days of their oviposition period, which, as shown in Table 8, follows a preoviposition interval of short duration. The postoviposition period is likewise brief, as a rule, but the oviposition period, especially in the case of females given drinking water, may be extended over a considerable time. On cool days, as shown in Table 10, few eggs are laid.

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TABLE 9.—*Fecundity of mated females of the Angoumois grain moth exposed in parallel series to contrasting moisture conditions, 1923 to 1925*

Eggs laid (number)	Number of females in each class interval			Eggs laid (number)	Number of females in each class interval		
	Normal conditions	High humidity	Drinking water supplied		Normal conditions	High humidity	Drinking water supplied
0	60	37	31	251–300		1	2
1–50	76	83	62	301–350			1
51–100	39	40	69	351–400			1
101–150	18	22	45				
151–200	5	9	25	Total	199	193	247
201–250	1	1	11				

TABLE 10.—*Typical examples from the oviposition records of the Angoumois grain moth*

[Pairs emerged and were mated Apr. 23, 1925]

Date	Number of eggs laid by 15 moths under specified conditions															Temperature			Mean relative humidity
	Normal conditions					High humidity					Drinking water supplied								
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	Mean	Maximum	Minimum	
																°F.	°F.	°F.	Per cent
Apr. 23	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	77	86	69	48
Apr. 24	----	----	----	6	----	----	15	71	----	----	(1)	1	42	----	----	84	91	79	48
Apr. 25	(2)	----	32	----	7	----	0	26	----	(3)	65	0	53	----	----	77	84	76	53
Apr. 26	----	----	19	----	12	----	10	34	1	----	0	2	38	----	----	76	80	72	56
Apr. 27	----	(2)	0	(2)	----	----	0	0	12	----	29	65	0	----	(3)	76	81	72	51
Apr. 28	(3)	----	2	----	----	----	9	3	38	----	18	12	0	----	----	68	76	62	48
Apr. 29	----	(3)	(3)	----	(3)	----	0	----	0	----	0	0	0	----	----	65	68	61	48
Apr. 30	----	----	----	----	----	----	4	----	0	----	0	[3] 0	19	----	----	66	81	54	44
May 1	----	----	(2)	----	(2)	----	[3] 3	----	[3] 5	----	15	13	6	17	----	79	82	73	31
May 2	----	----	----	(3)	----	9	8	----	7	----	(2)	5	1	10	----	75	79	72	31
May 3	----	----	----	----	----	4	3	----	0	----	----	0	(2, 3)	0	----	64	68	59	38
May 4	----	----	----	----	----	0	----	----	2	----	----	4	----	6	----	66	71	62	45
May 5	----	----	----	----	----	1	----	----	----	----	----	----	----	0	----	66	81	54	44
May 6	----	----	----	----	----	(3)	----	----	----	----	----	----	----	0	----	79	82	73	31
May 7	----	----	----	----	----	(2)	----	(2, 3)	(2)	----	----	----	----	1	----	75	79	72	31
May 8	----	----	----	----	----	----	----	----	----	----	----	(2)	----	(3)	----	64	68	59	38
May 9	----	----	----	----	----	----	----	----	----	(2)	----	----	----	----	----	66	71	62	45
May 10	----	----	----	----	----	----	(2)	----	----	----	----	----	----	----	----	65	68	61	48
May 11	----	----	----	----	----	----	----	----	----	----	----	----	----	(2)	----	72	74	70	62
May 12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	(2)	68	70	64	51
Total	0	0	53	6	19	14	52	134	65	0	127	102	159	34	0				

[1] Male escaped. [2] Female died. [3] Male died.

Owing probably to the moderate length of the oviposition period as compared with that of many insects, the batches of eggs deposited by Angoumois grain moths near the end of their egg laying do not exhibit decreased vitality, although the final egg or two laid shortly before the death of a female is likely to fail to hatch. The percentage of fertility of the eggs is generally high; 82.2 per cent of those recorded in Table 15 produced larvae.

INCUBATION PERIOD

Records of the incubation period of eggs from which 13,452 larvae hatched are assembled in Table 11. The minimum duration of the egg stage in this series was 4 days and the maximum 12 days, though,

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as noted on page 30, an incubation period of 17 days was recorded in the case of eggs exposed to a controlled temperature range of 60.8° to 64.4° F. The hatching of eggs laid the same day frequently extended over two days, and of some lots through three days.

TABLE 11.—*Incubation period of eggs of the Angoumois grain moth, 1923*

Lot No.	Date eggs were laid	Duration of incubation	Larvae hatched	Average daily temperature during incubation			Lot No.	Date eggs were laid	Duration of incubation	Larvae hatched	Average daily temperature during incubation		
				Mean	Maximum	Minimum					Mean	Maximum	Minimum
		Days	*Number*	*° F.*	*° F.*	*° F.*			*Days*	*Number*	*° F.*	*° F.*	*° F.*
1	Aug. 4	4	93	83.2	87.5	79.5	21	Aug. 27	6, 7	401	75.9	80.3	72.2
2	7	5	31	80.6	85.4	77.2	22	28	5, 6, 7	584	76.2	80.6	72.2
3	9	5	231	78.6	83.2	75.0	23	29	5, 6	700	76.0	80.7	71.7
4	10	5	663	78.2	82.6	74.6	24	31	6, 7	276	76.3	80.7	72.6
5	11	4, 5	370	79.0	83.6	74.8	25	Sept. 1	6, 7	368	75.7	79.9	72.3
6	12	5	281	78.8	84.0	74.4	26	2	6, 7	214	75.4	79.0	72.0
7	13	6	317	75.8	82.7	71.3	27	5	7, 8	169	67.0	72.0	68.5
8	14	7	176	75.6	82.3	71.0	28	6	9, 10	88	70.0	74.6	65.1
9	15	6	142	75.5	82.7	71.0	29	7	12	137	68.6	74.2	64.3
10	16	7	336	74.9	82.3	70.6	30	11	10	28	69.0	75.2	64.5
11	17	8	429	73.0	79.9	68.5	31	12	9, 10	1,132	69.9	75.7	64.9
12	18	8	198	73.1	80.0	68.6	32	13	9, 10	888	70.2	75.4	65.7
13	19	7, 8	474	73.1	79.2	68.4	33	14	9, 10	174	70.5	75.6	66.0
14	20	7, 8	614	73.1	79.1	68.7	34	15	9	112	71.3	75.9	66.7
15	21	7, 8	856	73.0	79.4	68.4	35	16	8, 9	163	72.7	75.9	68.3
16	22	7, 8	562	73.2	78.6	68.0	36	17	7, 8	175	73.9	78.2	70.0
17	23	7, 8	195	73.2	78.4	68.6	37	18	6, 7	229	75.1	79.0	72.0
18	24	8, 9	263	74.3	79.6	69.8	38	19	7	205	76.7	79.6	74.0
19	25	6, 7, 8	661	75.0	80.2	70.6	39	20	6, 7	182	76.7	79.6	74.0
20	26	6, 7	335	75.3	80.2	71.6							

LARVAL PERIOD

When ready to leave the eggshell the Angoumois grain moth larva gnaws away the small buttonlike process which intrudes into the egg cavity directly in front of the jaws of the doubled-up insect. This invagination is situated on the smaller and more deeply fluted end of the egg. The larva continues to bite away the shell until a ragged hole is formed through which it crawls to temporary freedom, leaving the hollow, rigid shell behind, the white shell appearing in marked contrast with the red of adjacent unhatched eggs.

Upon emergence the larva is white or buffy pink; traces of scarlet, apparently coloring the alimentary tract, show through the translucent tissues of the body. The larva crawls away steadily and purposefully, and when suitable food is encountered an "entrance cocoon" is frequently made (fig. 7), probably to furnish purchase for the work of excavating a tunnel into the hard seed. Entrance cocoons are less commonly made by larvae entering chaff-covered kernels.

When threshed wheat is attacked the entrance boring may be made at any point excepting the pubescent distal end, the groove of the seed being a favorite location. An examination of 113 kernels which had been infested before threshing revealed that 102, or 90 per cent, had been entered near the point of attachment of the kernel to the spike. Of these entrace holes, about two-thirds were in the groove and one-third on the germinal area.

As the larva progresses into the seed, the frass is packed into the entrance cocoon behind it, and the cocoon and the burrow become filled with white borings. Having penetrated to a depth about equal

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to its own length, the larva begins excavating and feeding upon the endosperm. The task of making the entrance burrow in the hard seed is, however, frequently so exhausting that the larva dies before its body is wholly within the seed. Mortality in young larvae is probably due more to this difficulty than to any other cause, and it doubtless accounts for the relative freedom from infestation of dry, hard grain.

Newly hatched larvae that are given no food or water live but a few days. One lot observed late in May succumbed within 4 days. Two lots which hatched late in July were all dead after 5 days, most of them having died during the first 3 days.

FIGURE 7.—Entrance cocoon made by a newly hatched larva of the Angoumois grain moth preparatory to boring into a kernel of wheat. The cocoon shown is filled with white borings. × 7

Examinations of infested wheat kernels made on consecutive days following infestation of the grain by newly hatched larvae in August, 1925, showed that the insects began to enter the second instar 5 days after they had hatched, and all had entered that stage 8 days after hatching. The change was indicated by the presence in the feeding cavity of the cast skins of the first-stage larvae. Similar records made in April, 1926, of insects reared at 77° to 80.6° F. in an incubator, showed that the change from the first to the second instar began as soon as 3 days after hatching, the third instar following about 10 days later.

FIGURE 8.—Full-grown Angoumois grain moth larva in a kernel of wheat. × 7 (Back)

In the fall of 1926 further observations were made by dissecting on consecutive days kernels from a lot started with newly hatched larvae on September 28 and subject to the temperature changes of the laboratory. The first instar occupied a minimum period of about 9 days, the second instar included the following 11 days, and the third stage began about 20 days after hatching took place. The remains of two cast skins continued to be found until November 3, on and following which date a few kernels were found to contain the remains of three skins, pointing to the progress of the larvae into the fourth instar. Pupation began November 10. In general the evidence leads to the conclusion that larvae of the Angoumois grain moth became full grown (fig. 8) at the end of their fourth instar, after having molted three times.

As the larva extends its excavation in the wheat kernel the cavity becomes partly filled with pellets of excrement among which the cast skins become mixed and broken. In many instances all of the endosperm is consumed, but it is probably more common to find only one

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of the halves of the seed eaten out. Of 225 kernels infested before threshing and in which feeding had been completed, the germ had been consumed in 223 kernels. On rare occasions two moths develop in a single wheat seed. Except in the cases of larvae in experimental planted wheat, full-grown larvae subjected to fumigation with carbon disulphide, and some instances in which the larvae apparently had fallen from exit holes, larvae have not been observed to leave the seed in which they developed.

At the time when the larva has become full grown the seed coat is entire, except for the minute entrance perforation, and is partly filled with frass. The larva forms as large a cavity as possible in the excavation, compacting the frass around it and leaving one end of the chamber in open communication with the seed coat. The cavity is then lined with a tough envelope of silk which flows from a spinneret located on a bulbous area between the labial palpi. In spinning, the larva swings its head from side to side, punctuating each swing with two or three forwardly directed pecking movements by which the thread is attached to several points. If larvae are removed from completed cells to glass vials, where their spinning may be observed, they are usually able to complete a second cocoon.

A most interesting phase of cocoon making within the wheat kernel is the making of the exit through which the adult will escape. This hole may be constructed at any point on the seed when threshed wheat is infested (fig. 2), but in wheat infested in the head all such openings observed by the writers were near the end of the seed opposite the point of attachment. Having cleared all of the seed contents from an area of seed coat of sufficient size, the larva cuts the testa for one-half or three-fourths of the periphery of a circle, thereby making a weakly fastened flap or doorway. The cutting has been observed to take place after the cocoon was completely formed, in which case the cocoon wall was cut in the same way, the flap of silk being folded back inside the seed. Ordinarily, however, the cut is made in the seed coat before the cocoon is completed, and the walls of the cocoon are extended to meet the edges of the opening, no silk being deposited on the inner surface of the lid.

It frequently happens that the disk of seed coat intended to serve as a trap door falls away, in which event the larva either closes the opening flush with a thin wall of silk or may extend the cocoon outward, forming an exit tube. (Fig. 9.) The only webbing together of seeds attributable to the Angoumois grain moth is caused by the construction of these exit tubes. More or less excrement from infested seeds falls from exit holes which remain open for a time when the normal process of exit making miscarries.

Just before pupation the final molt takes place. The compacted, entire skin is to be found pressed against the inner end of the pupal cell. (Fig. 10.)

Owing to the apparent impossibility of rearing larvae of the Angoumois grain moth otherwise than within hard kernels of grain, information about the length of the larval stage can best be secured by observing the time elapsing between the hatching of larvae from eggs, laid on pieces of cardboard and placed on uninfested grain, and the formation of the pupal cell or cocoon by the full-grown larvae. Cell formation is indicated on the surface of the seed by the circular

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FIGURE 9.—Wheat kernels fastened together by an exit tube of the Angoumois grain moth. × 7

FIGURE 10.—Pupa of the Angoumois grain moth within a cocoon spun between the cotton plug and the glass of a shell vial. The exit opening is at the right; the white object at the left of the pupa is the last larval skin. × 10

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cut made by the larva during or following the spinning of the cocoon. In Table 12 are given larval-period determinations made in this way, in corn.

TABLE 12.—*Duration of the larval period of the Angoumois grain moth in field corn, 1924*

Date eggs were laid	Maximum incubation period	Larval period	Average daily temperature during larval period			Date eggs were laid	Maximum incubation period	Larval period	Average daily temperature during larval period		
			Mean	Maximum	Minimum				Mean	Maximum	Minimum
	Days	*Days*	°*F.*	°*F.*	°*F.*		*Days*	*Days*	°*F.*	°*F.*	°*F.*
May 12	12	44	71.5	76.7	67.1	May 13	13	55	73.2	78.3	69.2
		34	70.6	75.9	66.1	May 14	13	35	71.8	77.3	67.6
		45	71.6	76.8	67.3			51	73.4	78.5	69.4
May 13	13	52	73.1	78.2	69.1			34	71.7	77.1	67.5
		55	73.2	78.3	69.2			33	71.5	76.8	67.3
		35	71.3	76.7	67.1						

The maximum incubation periods given in the table were usually one day longer than the minimum, a given lot of eggs generally hatching over a 2-day period. In the case of the few individuals whose records are shown in Table 12, the formation of the pupa occurred the day after cell construction was completed.

The variation in the lengths of the larval periods listed in Table 12 is seen to have been considerable and possibly was caused by differences in the hardness and dryness of the kernels of corn; but such variation is normal, as is shown by the scattering emergence records detailed in Table 17.

PUPAL PERIOD

As the time for the emergence of the winged insect approaches, the reddish-brown skin of the pupa splits open at the anterior end, the adult crawls forth, forces its way through the trap doorway, and, in its efforts to escape, frequently pulls the pupal case partly out of the seed. The duration of the pupal period was obtained by dissecting full-grown larvae from yellow corn and placing them in individual containers for pupation. The pupal cells were usually constructed against the glass of the containers (fig. 10), allowing examinations of the condition of the insects to be made. Table 13 gives the results of the experiment.

Two exceptional pupal periods of about three weeks are shown in Table 13. In the table no dates for pupal cell formation are given. After their removal from the corn, some of the larvae pupated without forming cells in the vials. The mortality incident to the unnatural conditions imposed upon the insects was high—about 66 per cent.

A second series of pupal-period records was obtained in 1926, by observing apparently full-grown larvae within wheat kernels that had been exposed to outdoor temperatures during the winter and placed in an incubator. (Table 14.) Pupation did not take place immediately after the larvae were placed in the incubator. It is probable that the insects had not completed feeding when their activity was halted by cold weather in the fall, or it may have been necessary for them to resume feeding in order to recoup energy lost by reason of slow metabolism during the period of dormancy.

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TABLE 13.—*Duration of the pupal period of the Angoumois grain moth as determined by isolating full-grown larvae dissected from corn, 1924*

Date of beginning of pupation	Date of emergence	Duration of pupal period	Sex	Average daily temperature during pupation		
				Mean	Maximum	Minimum
		Days		° *F.*	° *F.*	° *F.*
May 10	June 2	23	Female	64.9	71.2	58.6
May 29	June 13	15	do	65.3	70.5	60.6
June 9	June 17	8	Male	69.9	73.9	66.0
June 9	June 23	14	do	75.1	79.7	71.1
June 10	June 19	9	Female	72.1	76.3	68.1
June 10	June 22	12	do	75.2	79.8	71.1
June 10	do	12	Male	75.2	79.8	71.1
June 10	June 23	13	Female	75.5	80.1	71.4
June 12	June 22	10	Male	77.2	82.2	72.9
June 14	June 25	11	do	79.9	85.2	75.4
June 16	June 23	7	Female	81.4	86.7	77.1
June 20	June 27	7	do	82.0	87.0	79.1
June 21	July 1	10	Male	78.9	84.6	74.9
June 23	July 2	9	Female	77.4	83.1	73.5
June 23	do	9	do	77.4	83.1	73.5
June 26	July 8	12	Male	74.9	79.7	71.2
June 27	July 9	12	do	75.0	79.6	71.5
June 30	July 14	14	do	76.8	80.7	73.2
July 8	July 28	20	Female	78.8	83.9	74.7

TABLE 14.—*Duration of the pupal period of the Angoumois grain moth as determined by observations of pupae in wheat, at controlled temperatures of 75° to 80° F., 1926*

Date larva pupated	Pupal period	Sex of adult	Date larva pupated	Pupal period	Sex of adult	Date larva pupated	Pupal period	Sex of adult
	Days			*Days*			*Days*	
Mar. 23	5	Female.	Apr. 26	10	Male.	May 12	7	Female.
Mar. 23	5	Do.	Apr. 27	6	Female.	May 13	7	Male.
Mar. 23	5	Do.	Apr. 29	7	Do.	May 14	7	Female.
Mar. 28	8	Male.	Apr. 29	9	Male.	May 14	8	Male.
Mar. 30	9	Do.	Apr. 29	9	Female.	May 16	8	Female.
Apr. 4	8	Female.	May 3	7	Do.	May 16	6	Do.
Apr. 8	8	Male.	May 3	8	Male.	May 17	9	Do.
Apr. 23	7	Female.	May 4	9	Female.	May 17	7	Male.
Ayr. 24	6	Do.	May 5	6	Male.	May 18	7	Female.
Apr. 24	9	Male.	May 8	8	Do.	May 18	8	Male.
Apr. 24	8	Do.	May 9	7	Female.	May 20	9	Do.
Apr. 26	10	Female.	May 11	8	Do.	May 22	8	Female.

Average ..... 7.6 days

Because of the unfavorable effects of a dry atmosphere that would result to the insects directly, and also indirectly through the drying out of the food, a dish of water was kept in the incubator. The shortest period recorded (Table 14) was 5 days, and the maximum 10 days. The general average was 7.6 days, the males averaging 8.1 and the females 7.2 days.

DEVELOPMENT FROM HATCHING TO EMERGENCE

The most satisfactory records of the larval-pupal period were obtained from eggs laid in August and September, 1923, the larvae being reared in new wheat. Although the records are not based on dissections of kernels and, therefore, do not show the spans of the larval and pupal periods separately, they present a picture of the development of the species that is more extensive than any that could be obtained otherwise except by an impracticable number of dissec-

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tions of infested kernels. The data in Table 15 on the percentage of hatch and emergence were obtained by placing in vials partly filled with wheat pieces of cardboard bearing eggs, counting the eggs which hatched, and recording daily the emergence of adults.

TABLE 15.—*Development of Angoumois grain moths in wheat; each lot started with a known number of larvae hatched from eggs laid by one female on a known date, 1923*

Female No.	Date eggs were laid	Eggs laid	Eggs hatched		Emergence of adults			Larvae which became adult
					Males	Females	Total	
		Number	*Number*	*Per cent*	*Number*	*Number*	*Number*	*Per cent*
101	Aug. 27	78	75	96.2	32	30	62	82.7
102	do	43	20	46.5	8	9	17	85.0
103	Aug. 28	30	21	70.0	9	10	19	90.5
105	do	44	27	61.4	16	5	21	77.8
107	do	33	15	45.5	6	9	15	100.0
104	Aug. 29	77	71	92.2	17	23	40	56.3
105	do	38	29	76.3	23	5	28	96.5
103	do	14	13	92.9	5	5	10	76.9
107	do	7	6	85.7	4	1	5	83.3
103	Aug. 30	42	36	85.7	18	16	34	94.4
105	do	22	15	68.2	9	5	14	93.3
106	do	91	85	93.4	35	27	62	72.9
103	Aug. 31	22	18	81.8	10	8	18	100.0
104	do	10	8	80.0	3	5	8	100.0
107	do	12	9	75.0	4	5	9	100.0
104	Sept. 1	24	24	100.0	12	12	24	100.0
108	Sept. 17	53	53	100.0	22	18	40	75.5
112	do	45	45	100.0	17	19	36	80.0
114	do	22	18	81.8	8	10	18	100.0
116	do	18	14	77.8	5	3	8	57.1
109	Sept. 18	34	34	100.0	14	15	29	85.3
110	do	16	13	81.2	7	6	13	100.0
111	do	16	14	87.5	8	6	14	100.0
112	do	8	8	100.0	3	5	8	100.0
115	do	36	25	69.4	4	7	11	44.0
109	Sept. 19	16	16	100.0	8	5	13	81.2
110	do	93	61	65.6	19	16	35	57.4
111	do	31	29	93.5	15	7	22	75.9
114	do	19	19	100.0	5	5	10	52.6
115	do	40	30	75.0	6	8	14	46.7
116	do	21	15	71.4	1	10	11	73.3
111	Sept. 20	17	16	94.1	8	8	16	100.0
115	do	17	13	76.5	4	2	6	46.2
116	do	21	18	85.7	6	6	12	66.7
115	Sept. 21	17	13	76.5	3	4	7	53.8
117	do	17	17	100.0	9	8	17	100.0
109	Sept. 26	9	9	100.0	1	0	1	11.1
108	Sept. 27	5	4	80.0	2	0	2	50.0
113	do	7	7	100.0	0	0	0	0
121	Oct. 7	7	0	0	0	0	0	0
Total		1,172	963	82.2	386	343	729	75.7

Among the records included in Table 15 there are 10 instances of complete hatching of the eggs, and in 11 cases all the larvae which hatched attained the adult state. Of the larvae, 75.7 per cent became adults.

A summary of observations of rearings of a more extensive series is presented in Table 16. There is evidence in the first half of the table of high larval mortality, due probably to the dryness and hardness of the grain.

The minimum larval-pupal periods recorded for each lot of larvae are much the same as those shown in Table 5, in which the minimum time required for development by larvae liberated on growing wheat is seen to have been 29 days and the maximum 42 days.

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TABLE 16.—*Development of Angoumois grain moths in wheat from known numbers of newly hatched larvae, 1923*

Date hatching was completed	Larvae hatched	Adults emerged			Larvae that became adult	Minimum larval-pupal period	Date hatching was completed	Larvae hatched	Adults emerged			Larvae that became adult	Minimum larval-pupal period
		Males	Females	Total					Males	Females	Total		
	Number	*Number*	*Number*	*Number*	*Per cent*	*Days*		*Number*	*Number*	*Number*	*Number*	*Per cent*	*Days*
Aug. 14	231	36	28	64	27.7	35	Sept. 4	700	227	216	443	63.3	30
15	663	54	52	106	16.0	34	7	276	86	76	162	58.7	33
16	370	42	48	90	24.3	34	8	368	78	70	148	40.2	42
17	281	36	43	79	28.1	34	9	214	59	44	103	48.1	41
19	317	35	39	74	23.3	34	13	169	61	71	132	78.1	38
21	176	34	40	74	42.0	32	16	88	33	30	63	71.6	35
21	142	16	21	37	26.1	34	19	137	56	59	115	83.9	32
23	336	69	50	119	35.4	32	21	28	14	10	24	85.7	39
25	429	69	70	139	32.4	33	22	1,132	277	266	543	48.0	35
26	198	28	27	55	27.8	32	23	888	247	220	467	52.6	36
27	474	40	37	77	16.2	36	24	174	61	92	153	87.9	36
28	614	120	91	211	34.4	31	24	112	53	40	93	83.0	36
29	856	213	164	377	44.0	30	25	163	72	54	126	77.3	41
30	562	101	76	177	31.5	32	25	175	70	79	149	85.1	37
31	195	24	26	50	25.6	34	25	229	91	78	169	73.8	35
Sept. 2	263	19	17	36	13.7	38	26	205	82	89	171	83.4	38
2	661	33	46	79	11.9	37	27	182	74	63	137	75.3	37
2	335	103	90	193	57.6	33							
3	401	135	133	268	66.8	32	Total	13,328	3,003	2,790	5,793	43.5	30
4	584	155	135	290	49.7	30							

A representative group of the emergence records from which Table 16 was compiled is given in detail in Table 17.

Emergence occurred over a protracted period in all of the lots included in Table 16. Because of the presence, on frequent occasions, of individuals of both sexes in a single vial, reproduction occurred in the vials. For this reason the date on which emergence of the first brood of moths from each lot was completed has been approximated by arraying on a single sheet all of the detailed records. By this means a graphic picture of all emergence was obtained, and it was possible to draw a line separating the first brood from the beginning of the second, apparently with a considerable degree of reliability.

In Table 17 is shown the emergence records of the individuals from the lots which completed hatching from August 23 to August 29, as shown in Table 16.

The figures in Table 16 showing the minimum larval-pupal periods should be considered in the light of the scattered emergence shown in Table 17. The height of emergence was usually reached in two to three weeks after moths began to appear in each lot. The larvae in individual lots all began feeding activities within a day or two of the same time, and since they were exposed to the same temperatures, differences in the moisture content of the kernels would seem to be the chief variable which may be pointed to as an explanation of the wide interval between the first and the last emergence dates.

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TABLE 17.—*Typical examples of the progress of emergence of Angoumois grain moths from wheat, 1923*

Date of emergence	Date hatching was completed and number of adults emerged												Daily temperature		
	Aug. 23		Aug. 25		Aug. 26		Aug. 27		Aug. 28		Aug. 29				
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Mean	Maximum	Minimum
													° F.	° F.	° F.
Sept. 24	2												78	82	75
Sept. 25	1	3											78	81	74
Sept. 26	2												76	78	73
Sept. 27	1		1		1								75	78	72
Sept. 28	3	2		1					1		1	1	75	78	70
Sept. 29				1	1							1	73	77	68
Sept. 30	2	1	2	1	1						1		69	73	63
Oct. 1	1	1	5	2		1				1	2	2	69	73	64
Oct. 2	1	1	3	5			1			3	2	1	71	81	65
Oct. 3				1							2		70	73	64
Oct. 4	3	3	2	1	3			1	4		4	1	70	73	65
Oct. 5	2		3	4					1		2	1	71	88	60
Oct. 6		1	2	3		1	2	1	4	1	9	6	70	77	62
Oct. 7	2	1	1	2	3				2	1	3	3	66	73	62
Oct. 8											1	4	68	77	59
Oct. 9	2	3	2	4	2		2	2	4	2	9	3	72	76	67
Oct. 10	3		5	1			4		6	3	12	7	72	79	64
Oct. 11	4	3	1	5			1		2	4	13	9	76	82	70
Oct. 12	2	1	2	1	1				4		6	2	69	78	64
Oct. 13	5	5	1	3		1	1		1	5	8	12	68	73	63
Oct. 14	5	2	5	3	1	2	1	1	6	4	15	8	68	73	63
Oct. 15	4	1	1				1	1	2	1	7	1	70	72	68
Oct. 16	6	1	4	5	2	3	3	4	9	5	17	20	70	75	67
Oct. 17	4		3	3			4	1	4	10	15	14	69	79	63
Oct. 18	1	1	1						6	1	2	3	66	71	60
Oct. 19	2	2	6	2	2	2	1	2	12	7	7	9	71	82	62
Oct. 20		2	1	2	1	4	2		2	5	18	10	75	85	72
Oct. 21	2	7	2	5	2	4	2	5	10	4	13	10	68	78	60
Oct. 22		2	3		2			4	6	2	7	4	70	88	54
Oct. 23		4	1	1	2	1	7	3	7	2	7	9	72	88	61
Oct. 24	1		1		1	1			1	1	2	2	69	82	61
Oct. 25	2			2			2		5	2	2	1	75	88	66
Oct. 26	2			2	1	1	2		3	5	4	4	71	80	62
Oct. 27							1			5	1	2	72	82	60
Oct. 28	1	1	3	2	1	1	2		3	5	4	5	73	84	64
Oct. 29	1	1	3	1		3	1	1	4	1	7	2	81	90	74
Oct. 30	2		4	3	1			2	5	3	2	2	71	80	67
Oct. 31				1					2			1	69	88	53
Nov. 1				2		1		4	1	3	1		71	85	60
Nov. 2													65	84	48
Nov. 3		1	1	1		1			2			1	68	80	58
Nov. 4											1		59	70	53
Nov. 5													64	80	51
Nov. 6								2	1	1	3	1	72	78	67
Nov. 7								1		1	1		69	76	60
Nov. 8								1			1		68	82	58
Nov. 9								1		2			68	81	58
Nov. 10										1	1		68	75	60
Nov. 11													75	88	68
Nov. 12												2	67	75	62
Total	69	50	69	70	28	27	40	37	120	91	213	164			

EFFECTS ON DEVELOPMENT OF HIGH AND LOW TEMPERATURES

Some effects of constantly high temperatures, which ranged from 95° to 98.6° F., upon the eggs and mated adults of the Angoumois grain moth were determined in 1926. Eggs exposed to dry heat at these temperatures for 25 hours collapsed and did not hatch, but eggs incubated within this temperature range in a moist (saturated) atmosphere hatched poorly, beginning on the ninth day. The retarding effect of the high temperatures upon embryonic development appears when the 9-day incubation period is compared with the minimum of

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four days at temperatures of about 80°. Newly hatched larvae placed on wheat under temperatures of 95° to 98.6° failed to establish themselves in the grain.

A series of oviposition records was completed in 1926 at the same high temperature range. Some of the mated insects were exposed in dry vials, some were provided with a humid atmosphere, and others were given drinking water. For comparison with the fecundity and longevity of the pairs of moths kept in the incubator, a smaller number were kept in the laboratory in a humid atmosphere at room temperatures which ranged, during January, from 57° to 82°, with a mean of 69° F., and during February from 58° to 83°, the mean being 68°. A summary of the results of some of these observations is given in Table 18.

TABLE 18.—*Effects of a temperature range of 95° to 98.6° F. on the longevity and fecundity of mated pairs of the Angoumois grain moth, 1926*

Date of emergence and mating	Mated pairs	Average longevity		Average eggs laid
		Males	Females	
	Number	*Days*	*Days*	*Number*
NORMAL HUMIDITY				
Jan. 21	5	2.0	2.0	0
Jan. 23	5	2.0	2.2	0
Jan. 28	5	2.0	1.8	8
Feb. 9	5	2.0	2.2	0
Feb. 16	5	2.6	3.6	0
Feb. 24	5	3.0	3.2	0
Total or average	30	2.2	2.5	1.3
HIGH HUMIDITY				
Jan. 28	5	3.4	6.0	0
Feb. 9	5	3.4	4.8	0
Feb. 16	5	4.2	6.4	.4
Feb. 24	5	3.8	4.0	0
Total or average	20	3.7	5.3	.1
SUPPLIED DRINKING WATER				
Jan. 21	5	3.8	7.2	8.4
Jan. 23	[1] 5	7.2	10.0	33.2
Jan. 28	[1] 5	6.2	7.8	26.2
Feb. 9	5	3.0	5.4	8.4
Feb. 16	5	4.2	5.8	.4
Feb. 24	5	6.0	7.6	8.4
Total or average	30	[2] 5.0	7.3	14.2
CONTROL MOTHS AT ROOM TEMPERATURE AND HIGH HUMIDITY				
Jan. 22	6	15.8	21.5	22.5
Jan. 23	[1] 5	13.2	20.4	25.4
Total or average	11	[3] 14.8	21.0	23.8

[1] One male escaped.
[2] Computed from life span of 28 males.
[3] Computed from life span of 10 males.

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Several generalizations are suggested by Table 18. Temperatures of 95° to 98.6° F. are near the upper limit of the temperature range at which reproduction of the Angoumois grain moth occurs. Most females which are kept at these temperatures, in either a dry or a moist atmosphere, lay no eggs at all; but if drinking water is available, eggs are produced in small numbers. Although egg laying is not increased by raising the humidity to the saturation point, the lives of both sexes are extended. As a rule the females live longer than the males, but in dry heat both sexes succumb in about the same average short period.

Temperatures in the lower part of the reproductive range of the Angoumois grain moth were obtained by placing an electric incubator in a cold room in the fall and early winter, with the thermostatic control set to prevent the compartment from cooling to a point below a certain temperature. Two series of mated pairs were placed in the incubator at a temperature which ranged from 60.8° to 64.4° F., one series with drinking water and one without. The results of these tests are given in Table 19. It would appear that the provision of drinking water increased both the longevity of the moths and the prolificacy of the females. It is evident that 60.8° to 64.4° F. is near the lower part of the range of temperatures at which the species is able to reproduce.

TABLE 19.—*Effects of low temperatures on the fecundity and longevity of mated pairs of the Angoumois grain moth, 1926*

Date of emergence and mating	Temperature	Mated pairs	Average longevity		Average eggs laid	Remarks
			Males	Females		
	° F.	*Number*	*Days*	*Days*	*Number*	
Dec. 15	60.8–64.4	5	18.8	28.2	38.2	Water provided.
		6	9.3	14.2	7.5	Without water.

Mating was observed at the temperature of this test. Newly laid eggs placed in the cool incubator the day on which they were laid began to hatch on the seventeenth day, the longest incubation period recorded by the writers. A female moth, mated and placed in the incubator December 15, and given drinking water, lived 52 days, the longest adult life span observed during the investigation.

Below a temperature of 60° F. very few adults of the Angoumois grain moth emerge from their cocoons. The moths are sluggish at this temperature, usually remaining motionless, but they are able to crawl if disturbed.

COMPARATIVE RATE OF DEVELOPMENT OF THE SEXES

A compilation of the detailed records, a few of which were shown in Table 17, reveals the interesting fact that the larval-pupal period of male Angoumois grain moths tends to be shorter than that of the females. During the first 10 days of emergence from each lot, 590 males and 487 females appeared, an excess of males over females of 21 per cent. A similar grouping of the records for the last 10 days of emergence from each lot showed that 234 males and 341 females emerged, or 46 per cent more females than males. This is evidenced in the examples from the same records which are included in Table 17.

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During the first 10 days of emergence of each lot 85 males and 55 females were recorded, while 33 males and 45 females emerged during the last 10 days. The fact that males develop more rapidly than the females has been noted by Back (*1, p. 4*).

An excess of males over females appears to be the rule with this insect. The 729 adults recorded in Table 15 were 52.9 per cent males, and of 5,793 other newly emerged moths of which the sex was determined (Table 16) 51.8 per cent were males.

PARASITES

Parasites play a minor part in the repression of the Angoumois grain moth. At times hymenopterous parasites appear in large numbers, usually during an outbreak year, but after the moth has done most of its damage. The writers encountered such parasites but once, and then in small numbers. The species was identified by Robert Fouts as *Dibrachys boucheanus* Ratz. More can be said in favor of the activities of the mite *Pediculoides ventricosus* Newport, of which the Angoumois grain moth appears to be a favored host in the United States. On the other hand, *P. ventricosus* often becomes so abundant that its venomous attacks on man offset any possible benefit, and it is notoriously unwelcome to entomologists engaged in rearing Angoumois grain moths and certain other species.

OUTBREAKS, PAST AND FUTURE

Since *Sitotroga cerealella* first became established in the Carolinas more than 200 years ago, there have been long series of years during which the insect has been so reduced in numbers in some areas as to have been almost forgotten. Several observers of the rise and fall of the moth population have concluded that the chief influences that have determined the fluctuations have been exceptionally hot summers and cold winters. The writers have attempted (*9*) to arrive at an understanding of the effects of weather and other factors, using as a basis the excellent records of temperatures, time of wheat harvest, and moth abundance available for the area within a radius of 50 miles of Philadelphia.

A study of the records for this area in the 28-year period from 1897 to 1924 shows that four severe outbreaks occurred in 1898, 1901, 1921, and 1923, respectively; and that three very severe outbreaks marked the years 1900, 1908, and 1922. For purposes of temperature analysis the years were considered as having three seasons—winter (November–February), spring (March–May), and summer-fall (June–October). The character of the seasons was arrived at by combining the plus and minus departures of the monthly mean temperatures from the monthly normals. The following extract from the study referred to (*9*) summarizes part of the findings:

> The winter temperature figures show that bad moth years have usually been preceded by warm winters, but that even extreme winter mildness does not forecast an outbreak for the following summer. Of the 17 winters which were warmer than normal, but six preceded outbreaks, and the three warmest winters were not followed by outbreaks. On the other hand, no outbreaks followed the five coldest winters, which suggests that very cold winters have a strong influence in preventing the survival of enough moths to make possible heavy damage to the crop. Whether or not an unusually hot summer is able to overcome the repressive effect of a severe preceding winter remains to be demonstrated. The year 1920 does not afford a good example of such a condition because nearly all the

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excess temperature that accumulated during the summer-autumn of that year was recorded in October, at the end of the season of rapid moth increase. The absence of an outbreak in 1899 is quite significant, since a hot summer, accompanied by an early harvest, followed a winter that was colder than normal; and the lowest temperature of the 28 years (−6° F.) occurred in February of that year.

Spring temperature abnormalities do not show any decisive effect upon moth conditions. The spring is a time of rather slow development, principally in depleted and increasingly scattered holdings of bulk wheat and in diminished, though large and well distributed, stocks of ear corn. Two of the seven outbreaks followed cool springs, and of the 21 warm or normal springs but five were followed by outbreaks. Three of the four warmest springs were not precedent to unusual abundance of the insect. Although there can be no doubt that a warm spring provides good conditions for the development of the moths, the effect of such a spring appears to be subordinate to other influences.

The summer-autumn accumulated temperature departures bear a close relation to outbreaks. As the table shows, bad moth years have been marked by abnormally hot summer-autumn periods, without exception. No cool summer-autumn has been the occasion of an outbreak. The record-breaking heat of 1900 is correlated with an outbreak of maximum intensity.

Although there have been hot years without heavy losses from the insect, each of the five hottest summer-autumns during the past 28 years has been the occasion of an outbreak. In the seven outbreak years the Junes were all hotter than normal, and in five of them (1898, 1900, 1901, 1908, 1921) both June and July were abnormally hot. Conversely, from 1897 to 1924 there were six years (1898, 1900, 1901, 1908, 1913, 1921) in which both June and July were hotter than normal by more than 0.5° F., and five of them are known to have been outbreak years.

From the evidence at hand it seems fair to propose the hypothesis that in the absence of considerable above-normal temperature accumulations from June to October, all other influences favorable to the development of the Angoumois grain moth are incapable of causing an outbreak in the Philadelphia District. On the other hand, a large accumulated temperature excess during the summer and autumn is very likely to be accompanied by an outbreak, expecially if the preceding winter was mild and June and July unusually hot. Early harvests, which are related to hot weather in June, enable the moth to get an early start in the new crop of wheat; late harvests appear to forecast seasons of moderate or light losses from the insect.

In the future, occasional outbreaks of the moth may with reasonable certainty be expected as a result of the occurrence of sequences of abnormal weather such as those discussed in the foregoing quotation.

SUMMARY

In the winter-wheat region east of the Appalachian Mountains the farm supplies of corn and wheat, commonly on hand throughout the year, provide favorable conditions for the maintenance of a continuous population of the Angoumois grain moth. In occasional years of exceptionally hot summers outbreaks of the insect occur, causing losses to thousands of wheat growers. In addition to the wheat consumed by the insect or rendered unfit for food, there are reductions in yield brought about by the planting of infested kernels. Corn serves as an important reservoir of infestation, but is not damaged to a serious degree. Infestation of corn begins in the field. Barley, rye, and other seeds are sometimes injured.

The insects survive the period of unfavorably cold weather—about six months long in Maryland—for the most part as larvae inclosed in kernels of grain in storage and in scattered wheat in litter, straw piles, and baled straw. Winter mortality appears to be high. No survival in planted wheat is indicated.

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Emergence of the adults begins about the middle of May. Some of the moths which emerge before wheat harvest fly to the fields to deposit eggs upon the developing grain. After this, harvested grain is attacked, both before and after threshing. The second brood of adults appears soon after wheat harvest, which begins in late June or early in July. Infestation increases most rapidly during July and August. The rate of increase depends chiefly on the temperature and upon the procedure followed by individual farmers. As the weather gets colder breeding is progressively retarded and reaches a standstill early in November. Of the influences that antagonize the species, parasites are relatively unimportant.

Young larvae of the Angoumois grain moth are able to establish themselves on wheat before the plant has blossomed and even before the heads appear. For this reason clean-up operations to reduce moth sources on farms should be completed before the wheat is headed, preferably before May 1. Although infestations of standing wheat expressed as percentages usually are small, they represent large populations per acre. Upon this widespread field infestation depends the ability of the insect to cause commercial damage.

Infestation of field corn at harvest time is general but light, being confined for the most part to the exposed tips of ears grown near sources of moths in and about farm buildings.

The lives of the adults are comparatively brief. The females, which live slightly longer than the males, normally produce most of their eggs within a week after mating. The average number of eggs laid under dry conditions is about 40, but high atmospheric humidity brings about an increase to about 50 eggs, whereas moths supplied with drinking water produce about 80 eggs. Many females lay much larger numbers, a few of them more than 300. Temperatures of 95° and 64° F. are near the upper and lower limits, respectively, of the reproductive range of the species.

In hot weather the eggs hatch after an incubation period of from four to eight or more days. The newly hatched larva bores into the host seed within a short time and thereafter feeds entirely within the grain. Pupation takes place in a silken cocoon constructed in the cavity which results from larval feeding. The adult emerges through a circular trap door previously prepared by the full-grown larva. The development of the insect, from hatching to emergence, may be completed in as short a time as 29 days, but longer developmental periods are the rule, and the rapidity of the growth and metamorphosis of individuals which hatch on the same day varies markedly. The length of time spent in feeding and transformation by the females is somewhat longer than that required by the males. Males and females comprise, respectively, about 52 and 48 per cent of the moth population.

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LITERATURE CITED

(1) Back, E. A.
1929. ANGOUMOIS GRAIN MOTH. U. S. Dept. Agr. Farmers' Bul. 1156, 18 p., illus. (Revised.)

(2) Ball, C. R., Leighty, C. E., Stine, O. C., and Baker, O. E.
1922. WHEAT PRODUCTION AND MARKETING. U. S. Dept. Agr. Yearbook 1921:77–160, illus.

(3) Candura, G. S.
1926. CONTRIBUTO ALLA CONOSCENZA DELLA VERA TIGNOLA DEL GRANO (SITOTROGA CEREALELLA OLIV.). Bol. Lab. Zool. Gen. e Agr. R. Scuola Super. Agr. Portici 19:[19]–102, illus.

(4) Duhamel du Monceau, [H. L.], and Tillet, [M.]
1762. HISTOIRE D'UN INSECTE QUI DEVORE LES GRAINS DE L'ANGOUMOIS AVEC LES MOYENS QUE L'ON PEUT EMPLOYER POUR LE DÉTRUIRE. 314 p., illus. Paris.

(5) Ellington, G. W.
1930. A METHOD OF SECURING EGGS OF THE ANGOUMOIS GRAIN MOTH. Jour. Econ. Ent. 23:237–238, illus.

(6) King, J. L.
1920. THE ANGOUMOIS GRAIN MOTH. Penn. Dept. Agr., Bur. Plant Indus. Circ. 1, 14 p., illus.

(7) Réaumur, [R. A. F.] de
1736. MÉMOIRES POUR SERVIR À L'HISTOIRE DES INSECTES. v. 2, 514 p., illus. Paris.

(8) Simmons, P., and Ellington, G. W.
1924. BIOLOGY OF THE ANGOUMOIS GRAIN MOTH—PROGRESS REPORT. Jour. Econ. Ent. 17:41–45.

(9) ——— and Ellington, G. W.
1925. THE CAUSES OF OUTBREAKS OF THE ANGOUMOIS GRAIN MOTH. Jour. Econ. Ent. 18: 309–320, illus.

(10) ——— and Ellington, G. W.
1927. DISPERSION OF THE ANGOUMOIS GRAIN MOTH TO WHEAT FIELDS. Jour. Agr. Research 34:459–471.

(11) United States Department of Agriculture, Weather Bureau.
1926–27. CLIMATOLOGICAL DATA, DELAWARE AND MARYLAND SECTION. October, 1926, to April, 1927, Washington, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SUDAN GRASS AS HAY, SILAGE, AND PASTURE FOR DAIRY CATTLE

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INTRODUCTION

Sudan grass is an important hay and pasture crop of the Middle West and Southwest because it is drought and heat resistant. It makes its greatest growth and produces the most feed during July, August, and September, when native grasses are less productive.

The usual farm practice in making Sudan-grass hay is to cut it when the seeds in the heads are in the milk or soft-dough stage. One and sometimes two cuttings, depending on the season, are obtained when the hay is cut at this stage. This procedure results in a coarse, stemmy hay, and dairy cattle refuse to eat probably 25 per cent of it by weight. Considerable information has heretofore been available on the comparative yields of Sudan-grass hay cut at different stages of maturity,[1] [2] but data indicating the comparative feeding value for dairy cattle are limited.

Previous experiments with Sudan grass at the Woodward station [3] have shown that as pasture it exceeded winter wheat, winter rye, and

[a] The work of the Woodward Dairy Experiment Station is carried on by the Bureau of Dairy Industry in cooperation with the Oklahoma Agricultural and Mechanical College. Specialists of the Bureau of Plant Industry, on the staff of the Dry Land Experiment Station, at Woodward, Okla., rendered advice on the stages for cutting the hay. Charles B. Parker, junior chemist, Bureau of Dairy Industry, conducted the analytical work.

[1] VINALL, H. N. SUDAN GRASS. U. S. Dept. Agr. Farmers' Bul. 1126, 21 p., 10 fig., 1931.

[2] VINALL, H. N., and GETTY, R. E. SUDAN GRASS AND RELATED PLANTS. U. S. Dept. Agr. Bul. 981, 68 p., 25 fig. 1921. (This bulletin contains a detailed account of the introduction of Sudan grass and several other species of grass sorghums, as well as a summary of the results of numerous experiments with Sudan grass in the United States.)

[3] STAUBER, C. J., STUART, D., and GRAVES, R. R. DAIRY WORK AT THE WOODWARD FIELD STATION, WOODWARD, OKLA., 1921 to 1926. U. S. Dept. Agr. Circ. 12, 24 p., illus. 1927.

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sweetclover in nutrients produced and value per acre. As a hay crop it exceeded cowpeas in yield and nutrients produced per acre, but was exceeded by Sunrise kafir and Red Amber sorgo in yield and nutrients produced per acre.

FIGURE 1.—Sudan-grass hay cut at three stages of maturity: A, first-heads-out stage; B, full-head stage C, milk or soft-dough stage

PLAN OF INVESTIGATIONS

In 1928 experiments were started at the Woodward (Okla.), Dairy Experiment Station to compare the yields of nutrients per acre and to compare the feeding values for milk production of Sudan-grass hay

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harvested (1) when heads first appeared, (2) when fully headed, and (3) when the seeds were in the milk or soft-dough stage. Field records have been secured for three years (1928 to 1930, inclusive), on the full-head and soft-dough stages and for four years (1928 to 1931, inclusive), on the first-heads-out stage. For two years (1929 and 1930) data were secured on the yields of Sudan-grass hay cut approximately every 30 days. Feeding experiments comparing the feeding values of the hay made from the various stages were conducted for the two years 1928 and 1929, and in addition, for the years 1929 and 1931, respectively, Sudan grass cut in the full-head and first-heads-out stages was ensiled, and groups of cows were fed in such manner as to obtain a comparison of the hay and the silage both made at the full-head and first-heads-out stages.

Additional data were secured in 1928 to 1931, inclusive, on the carrying capacity and milk production per acre for Sudan grass as a pasture crop, and these data are included and are interpreted on a comparative basis with the yields and nutrients produced by Sudan grass as a hay crop

FIELD EXPERIMENTS WITH SUDAN GRASS CUT AT DIFFERENT STAGES OF MATURITY

For these experiments similar plots of land of approximately 0.675 acre each were laid out and seeded (drilled) to Sudan grass. The seeding date was June 1 for 1928 and 1929, May 22 for 1930, and June 8 for 1931, and the seed was sown at the rate of 12 pounds per acre. The plots had received no fertilizer treatment and were comparable in every way. The hay was cut at the stages previously mentioned, unless otherwise noted (fig. 1), allowed to cure in the field, and then cocked for several days, after which it was carefully weighed and stacked. The weights obtained when the hay was stacked were considered as field-cured weights.

TABLE 1.—*Comparison of yields of Sudan-grass hay from similar plots cut at three different stages of maturity, 1928*

Item	Stage		
	First heads out	Fully headed	Milk or soft dough
Date of seeding	June 1	June 1	June 1
Date of—			
First cutting	July 19	Aug. 3	Aug. 15
Second cutting	[1] Oct. 5	[1] Oct. 5	[1] Oct. 5
Length of time between—			
Sowing and first cutting ... days	48	63	75
First and second cuttings ... do	[1] 78	[1] 63	[1] 51
Field-cured hay (weight as stacked):			
First cutting ... pounds per acre	3,409	4,180	4,217
Second cutting ... do	1,245	709	226
Total field-cured hay ... do	4,654	4,889	4,443
Total air-dry hay [2] ... do	3,723	3,911	3,554

[1] On account of an unfavorable growing season, this cutting did not represent the stage indicated Second; cuttings were all made on the same date.

[2] Calculated on the basis of loss of 20 per cent in moisture. This is the average loss for 1930.

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Representative samples of each cutting were obtained at the time of weighing and stacking. The samples were placed in muslin bags and were hung up to dry until they were thoroughly air-dry. Yields of air-dry hay per acre were calculated from the loss in weight of the samples from the field-cured to the air-dry basis. For 1928, only the field-cured weight was obtained, but the air-dry weight was calculated from the loss in weight of the samples for 1930. The air-dry samples were sent to the Washington, D. C., laboratory for chemical analyses.

Tables 1 and 2 give the essential field records on the hay cut at the indicated stages for 1928 to 1930.

TABLE 2.—*Comparison of yields of Sudan-grass hay from similar plots cut at four different stages of maturity in 1929 and 1930*

Item	Stage			
	First heads out		Full head	
	1929	1930	1929	1930
Date of seeding	June 1	May 22	June 1	May 22
Date of—				
First cutting	July 17	July 8	July 31	July 19
Second cutting	Aug. 28	Aug. 14	Oct. 21	Oct. 9
Third cutting	Oct. 21	Oct. 9		
Fourth cutting				
Length of time between—				
Sowing and first cutting ... days	46	47	60	58
First and second cuttings ... do	42	37	82	82
Second and third cuttings ... do	54	56		
Third and fourth cuttings ... do				
Air-dry hay:				
First cutting ... pounds per acre	2,492	1,739	2,908	1,952
Second cutting ... do	970	317	1,932	1,072
Third cutting ... do	1,710	1,147		
Fourth cutting ... do				
Total air-dry hay ... do	5,172	3,203	4,840	3,024

Item	Stage			
	Milk or soft dough		Cut every 30 days	
	1929	1930	1929	1930
Date of seeding	June 1	May 22	June 1	May 22
Date of—				
First cutting	Aug. 10	July 30	July 5	June 30
Second cutting	[1] Oct. 21	Oct. 9	Aug. 5	Aug. 8
Third cutting			Sept. 10	Sept. 12
Fourth cutting			Oct. 10	Oct. 20
Length of time between—				
Sowing and first cutting ... days	70	69	34	39
First and second cuttings ... do	[1] 72	71	31	39
Second and third cuttings ... do			36	35
Third and fourth cuttings ... do			30	38
Air-dry hay:				
First cutting ... pounds per acre	3,483	2,021	689	1,296
Second cutting ... do	[1] 1,648	1,061	1,334	810
Third cutting ... do			437	846
Fourth cutting ... do			583	240
Total air-dry hay ... do	5,131	3,082	3,043	3,192

[1] This cutting did not quite reach the full-milk or soft-dough stage.

In 1929, the second cutting from the plot used for the soft-dough-stage hay did not quite reach that stage. The 30-day-stage hay in

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1930 represented a somewhat longer growing period than 30 days, the four cuttings averaging 38 days' growth. For 1929 the four cuttings of 30-day-stage hay averaged 33 days in growth. For convenience, however, it is hereafter referred to as 30-day-stage hay.

The difference in growth as represented by the number of cuttings for the three respective years is explained by the amount of rainfall during the growing period for those years. This is shown in Table 3.

TABLE 3.—*Record of rainfall during 5-month growing period, Woodward, Okla., 1928 to 1931, inclusive*

Year	Rainfall (inches)					
	May	June	July	August	September	Total for 5 months
1928	6.69	3.74	1.42	0.35	0.81	13.01
1929	3.41	.58	3.15	2.09	4.45	13.68
1930	7.78	2.93	.23	1.42	1.06	13.42
1931	3.44	2.69	1.13	1.53	2.86	11.65

July, August, and September are the three months when rain is most needed for recovery and growth after cutting. For this reason the yields of hay in 1929 are materially higher than the yields in 1928 and 1930.

Records were kept for 1931 on the yields of Sudan-grass hay cut at first-heads-out stage only and are as follows:

Seeded	[4] May 29
First cutting	July 22
Second cutting	Sept. 2
Third cutting	Oct. 22
Days between reseeding and first cutting	44
Days between first and second cuttings	42
Days between second and third cuttings	50
Air-dry hay per acre, first cutting (pounds)	1,239
Air-dry hay per acre, second cutting (pounds)	499
Air-dry hay per acre, third cutting (pounds)	833
Total air-dry hay per acre (pounds)	2,571

The yield of 2,571 pounds of air-dry hay per acre in three cuttings is considerably lower than that of the hay cut in the three previous years at the same stage. The fact that this yield was lower was due largely to a shortage of moisture. In 1931 the rainfall was only 11.65 inches for the five months May to September, inclusive, while in each of the three years previous, the rainfall slightly exceeded 13 inches for these months. Then too, in 1931 the Sudan grass had to be reseeded. It was originally planted on May 29, but 1.9 inches of rain fell on June 5 and washed out most of the seed.

The yields of hay from the different stages of maturity are surprisingly close by years. Judging by the yields in the three years in which hay of the three stages of maturity was made, there is no material difference in the acre yields of air-dry hay. For these three years the average yield per acre was 4,033 pounds of first-heads-out hay, 3,925 pounds of fully headed hay, and 3,922 pounds of soft-dough-stage hay. The average yield of hay cut approximately every 30 days during 1929 and 1930 was 3,117 pounds. This is considerably lower than the 3-year average for the hay cut at the other three stages

[4] Reseeded June 8.

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of maturity. In 1929 the yield of the hay cut every 30 days was markedly lower, but in 1930 it was practically the same as that for the other three stages. These yields are somewhat lower but compare favorably with yields of Sudan-grass hay reported from the Fort Hays Experiment Station, Hays, Kans.[5]

As previously stated, the hay was weighed as taken from the field before it was made into small stacks of approximately 3 tons. From the difference between the weight of the hay as taken from the field, its weight on an air-dry basis, and the amount of moisture remaining in the air-dry sample, the moisture content of the field-cured hay was calculated. These results indicate that some of the cuttings went into the stack containing as high as 46 per cent moisture. This is much higher than is ordinarily considered safe for stacking or placing in the mow. With the exception of a small amount of the second cutting from the first heads-out plot for 1929 the hay was not damaged by heating. No browning of the hay, such as would occur in "tobacco-cured" alfalfa was noted.

CHEMICAL COMPOSITION AND PROTEIN CONTENT

The chemical composition of the hays cut at the different stages in 1928, 1929, and 1930 is given in Table 4.

In two of the three years the percentage of crude protein in the first cutting was materially greater for the hay cut at the first-heads-out stage than for the full-head and soft-dough stages, but in 1930, the hay cut at the full-head stage was somewhat higher in crude protein. Due to the short growing season in 1928 the Sudan grass, after the first cutting on July 19, did not reach the stage of maturity desired before danger of frost was imminent. Consequently, the second cutting on all three plots was made on October 5.

In 1928 the period between the time of first cutting and the date, October 5, when the Sudan grass on all three plots was cut, was 51 days for the soft-dough plot; 63 days for the full-head plot, and 78 days on the first-heads-out plot. (Table 1.) In periods of time for growth the plots were actually reversed from what they were at the time of the first cutting. While days' growth is not always a criterion of stage of growth reached, in this instance both the crude-protein and crude-fiber content follow very closely the days' growth in reverse order, the hay being highest in protein content and lowest in crude fiber for the 51 days' growth (second cutting, soft-dough stage, 1928) and lowest in percentage of protein and highest in crude fiber for the 78 days' growth (second cutting, first heads out, 1928).

In 1929 three cuttings were obtained on the plot cut when first headed out. The soft-dough plot, cut first on August 10 (Table 2), again failed to reach the soft-dough stage when growth stopped on October 21. Consequently the hay on this plot represented a shorter period of growth at the second cutting (72 days) than did the hay from the full-head plot (82 days). The effect of stage of maturity is again reflected, as it was in the 1928 cuttings, in the crude-protein and crude-fiber content following the period of growth, but in reverse order. The protein content decreased as the period of growth advanced, while the crude-fiber content increased. The period of growth at the time of the second cuttings on the full-head and soft-dough plots was longer in 1929 than in 1928, yet the percentage of

[5] VINALL, H. N. SUDAN GRASS. U. S. Dept. Agr. Farmer's Bul. 1126. p. 13, 1931.

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TABLE 4.—*Chemical composition of Sudan-grass hay (dry-matter basis) cut at different stages of maturity and yields of dry matter and crude protein, 1928–1930*

Year and stage of maturity	Composition of each cutting																Yield per acre of—	
	Crude protein in—				Ether extract (fat) in—				Crude fiber in—				Nitrogen-free extract in—					
	First	Second	Third	Fourth	First	Second	Third	Fourth	First	Second	Third	Fourth	First	Second	Third	Fourth	Dry matter[1]	Crude protein
1928	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Pounds*	*Pounds*
First heads out	12.5	6.8	-------	-------	2.10	1.37	-------	-------	30	34	-------	-------	47	50	-------	-------	3,351	367.6
Full head	8.5	6.9	-------	-------	1.59	1.48	-------	-------	34	32	-------	-------	47	51	-------	-------	3,520	291.0
Soft dough	5.8	8.5	-------	-------	1.57	1.58	-------	-------	34	30	-------	-------	52	52	-------	-------	3,199	195.0
1929																		
First heads out	13.4	12.4	10.7	-------	1.33	2.01	1.85	-------	33	28	30	-------	40	45	46	-------	4,655	573.5
Full head	8.3	10.3	-------	-------	1.93	1.77	-------	-------	32	31	-------	-------	50	47	-------	-------	4,356	396.3
Soft dough	8.0	11.8	-------	-------	1.92	1.74	-------	-------	35	29	-------	-------	49	41	-------	-------	4,618	425.7
Cut every 30 days	14.2	9.4	14.1	16.7	1.12	2.45	2.23	1.58	19	28	29	27	27	51	43	37	2,739	344.0
1930																		
First heads out	9.5	11.3	8.6	-------	2.16	2.39	1.21	-------	29	26	30	-------	52	53	47	-------	2,883	269.7
Full head	10.6	8.3	-------	-------	2.11	1.54	-------	-------	26	33	-------	-------	53	49	-------	-------	2,722	266.3
Soft dough	7.8	9.6	-------	-------	1.97	1.66	-------	-------	30	30	-------	-------	55	49	-------	-------	2,774	233.5
Cut every 30 days	12.7	10.8	17.2	(2)	2.31	2.28	2.32	(2)	27	19	25	(2)	50	46	42	(2)	2,873	383.2

[1] Air-dry hay averaged 10 per cent moisture.
[2] No sample.

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protein was higher for the hay cut from these plots in 1929, and the percentage of crude fiber was lower. This would seem to be contradictory to the results that have just been pointed out as due to length of period of growth. It has been found, however, that the absence of moisture will also affect these elements, prolonged dry weather depressing the percentage of protein. The rainfall was very light in August and September in 1928 and was much heavier in the same months in 1929. This would probably account for the greater percentage of protein in the second cuttings in 1929 notwithstanding the longer period of growth, as compared with the second cuttings in 1928. Other conditions might have been responsible for retarding the maturation of the plants in 1929.

The average crude-protein content for the three years of the three respective stages for first cuttings only is:

	Per cent
First heads out	11.8
Full head	9.1
Soft dough	7.2
Cut every 30 days (1929 and 1930 only)	13.5

The hay cut every 30 days was higher in crude protein in 1929 than the first heads out and other stages, in all but the second cutting, which contained only 9.4 per cent of crude protein. Since the crude-fiber content of this cutting was low, it is probable that the sample analyzed was not typical. The average crude-protein content of the four 30-day cuttings for 1929 was 13.6 per cent.

In 1930 the hay from the first three cuttings of the 30-day hay averaged 13.6 per cent protein, the same as did the four cuttings for 1929. In 1930 the 30-day hay averaged 37 days' growth, while in 1929 it averaged only 33 days' growth.

Table 5 was compiled to show more clearly the relation of the chemical composition of the Sudan-grass hay to the number of days' growth. This table shows the average composition of all samples analyzed, arranged approximately by 10-day growth periods at time of cutting, which ranged from 30 to 82 days.

TABLE 5.—*Average composition of Sudan-grass hay arranged according to 10-day growth periods, dry-matter basis*

Days of growth	Samples of hay analyzed	Nutrients			
		Crude protein	Ether extract (fat)	Crude fiber	Nitrogen-free extract
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*
30 to 40	8	13.3	2.08	31	44
41 to 50	4	11.9	1.90	30	46
51 to 60	4	9.6	1.69	29	49
61 to 70	4	7.9	1.74	32	51
71 to 82	7	8.7	1.65	32	48

The percentage of protein decreased with advance in days' growth, as was to be expected, except in those samples representing a growth of 71 days and over, which are a little high. The ether extract (fat) also decreased consistently with advance in number of days' growth. The crude-fiber content for the two periods of 30 to 40 days and 41 to 50 days is higher than was to be expected, in view of the percent-

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ages shown for the last three 10-day growth periods. The nitrogen-free extract increased steadily with the advance in days' growth. A part of this increased percentage may have been due to the formation of nutrients in the seeds. The nitrogen-free extract is lower and the crude protein is somewhat higher for the last period than was to be expected for 71 to 82 days' growth. Five of the seven samples analyzed for this period were from second cuttings, and the analysis probably indicates that weather conditions so affected the growth that the second-cutting hay was less mature (according to head formation) with 71 to 82 days' growth than was the hay with a growth period of 61 to 70 days.

YIELDS OF DRY MATTER AND PROTEIN PER ACRE

In 1928 the yield of crude protein per acre was 367.6 pounds for the first-heads-out stage, 291 pounds for the full-head stage, and only 195 pounds per acre for the soft-dough-stage hay. (Table 4.) This is an increase of 172 pounds, or 88 per cent, in favor of the first-heads-out hay over the soft-dough-stage hay.

In 1929, because of the greater yields of dry matter and higher crude-protein content, the yields of crude protein per acre were materially greater than in 1928. First-heads-out hay ranked first again, with an increase of 45 per cent over the full-head hay, and 35 per cent over the soft-dough-stage hay. Owing to poor recovery after cutting and consequent low yields of air-dry hay, the yield of crude protein for the 30-day-stage hay was 344 pounds per acre. In 1930, however, the reverse was true.

The average yields of crude protein per acre for the various cuttings for the three years were as follows:

	Pounds per acre
First heads out	403. 6
Full head	317. 8
Milk or soft dough	284. 7
30-day stage (2 years)	363. 6

The average of the three years' yields for each stage shows an advantage of 85.8 and 118.9 pounds, respectively, of crude protein per acre of first-heads-out hay over the full-head and soft-dough stages. These represent increases of 27 and 42 per cent, respectively. One acre of Sudan-grass hay cut at the first-heads-out stage yielded as much crude protein as 1.27 acres of hay cut when fully headed and as much as 1.42 acres when cut in the milk or soft-dough stage.

The average yields of crude protein of the two years (1929 and 1930) in the hay cut approximately every 30 days was 363.6 pounds, second only to the first-heads-out hay.

FEEDING EXPERIMENTS WITH HAY

During the winters of 1928 and 1929 feeding trials were conducted with groups of registered Holstein-Friesian cows with the Sudan-grass hay which had been cut at the different stages of maturity the previous summer. All groups were made up of three milking cows each, and the groups were balanced as nearly as possible according to age, size, stage of lactation, etc. The respective hays were fed to each group ad libitum, and no attempt was made to force them to

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eat the stemmy or unpalatable portion of the hay. That portion of the hay refused was carefully weighed daily, and samples of the refused portion were taken for analyses. All of the cows were accustomed to eating Sudan-grass hay.

A grain mixture, made up of 4 parts ground kafir, 4 parts wheat bran, 1 part linseed meal, and 1 part cottonseed meal was fed to each group at the rate of 1 pound of grain to 5 pounds of milk produced.

A good quality of kafir silage was fed at the rate of 1 pound of silage per 100 pounds of body weight. The silage was limited to insure a higher consumption of hay.

The feeding periods lasted for 28 days, preceded by a 7-day preliminary period to accustom the cows to the feed. During the preliminary period all groups of cows were fed the feeds at the rate given. While these periods are shorter than was desired, it was the best that could be done under prevailing circumstances.

During 1928 groups 1, 2, 3, and 4 were fed simultaneously. The first cutting only of the various stages of Sudan-grass hay was fed. During 1929, groups 1, 2, 3, and 5 were fed simultaneously, and the alfalfa-hay check group was fed later in the winter. Some hay from all cuttings of each stage of maturity was fed during 1929.

The alfalfa hay fed the check groups was locally grown creek-bottom hay that would grade as United States No. 1. The alfalfa hay fed during 1929 was thought to be of slightly better quality than that fed in 1928. However, the crude-protein content of the alfalfa hay fed in 1929 was only 15.3 per cent whereas that fed in 1928 was 17.6 per cent.

The groups were all fed and handled under similar conditions. All cows had been raised on the experimental farm and were of similar breeding. They were accustomed to eating all of the feeds used in this experiment. They were milked twice each day. All feed was fed in mangers in the barn. Conditions other than the kind and quality of the hay fed were maintained as comparable as possible with the number of available animals.

Table 6 gives the essential data concerning age, weight, and production of the cows by groups.

The groups were fairly well balanced according to age, stage of lactation, and average daily milk production, for the respective years. The average number of days in milk, however, was considerably greater for the 1928 groups than for the 1929 groups. The cows used in 1928 averaged 205 days in lactation, while those in 1929 averaged only 138 days in lactation. The average daily milk production at the beginning of the trials was almost 10 pounds less per day for the cows used in 1928 than for the cows used in 1929. The body weight averaged 24 pounds per cow greater for 1929 than for 1928 at the beginning.

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TABLE 6.—*Average age, body weight, feed consumption, and milk production of groups of cows fed Sudan-grass hay cut at various stages of maturity, 1928 and 1929*

Stage of cuttings, group, and year	Average age of cows	Stage of lactation at start	Average daily milk yield at start [1]	Hay fed in 28 days	Hay consumed— In 28 days	Hay consumed— Per cow per day	Hay refused in 28 days		Grain consumed in 28 days
	Years	*Days*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Per cent*	*Pounds*
First heads out:									
Group 1, 1928	6	158	25.1	3,000	2,409	28.6	591	19.7	380.8
Group 1, 1929	6½	136	34.7	3,335	2,807	33.4	528	15.8	562.8
Full head:									
Group 2, 1928	5½	196	22.0	2,490	1,642	19.5	848	34.0	324.1
Group 2, 1929	4	150	33.9	3,300	2,626	31.4	674	20.4	503.0
Soft dough:									
Group 3, 1928	4½	232	25.3	2,490	1,737	20.6	753	30.2	360.5
Group 3, 1929	5	135	32.3	3,300	2,693	32.0	607	18.3	491.4
Cut every 30 days:									
Group 5, 1929	5½	131	33.5	3,265	2,726	32.4	539	16.5	547.4
Alfalfa check:									
Group 4, 1928	5	234	23.1	2,380	2,288	27.2	92	3.8	347.9
Group 4, 1929	5½	132	33.4	2,777	2,747	32.7	30	1.1	568.4

Stage of cuttings, group, and year	Silage consumed in 28 days	Milk produced— In 28 days	Milk produced— In first 7 days	Milk produced— In last 7 days	Increase (+) or decrease (−) in milk yield		Average body weight per cow— At beginning	Average body weight per cow— At end	Average body weight per cow— Increase (+) or decrease (−)
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*	*Pounds*
First heads out:									
Group 1, 1928	1,172.5	1,861.9	490.2	449.2	−41.0	−8.4	1,398	1,410	+12
Group 1, 1929	1,131.9	2,806.5	701.9	701.4	−.5	−.1	1,347	1,333	−14
Full head:									
Group 2, 1928	1,064.0	1,536.0	409.6	365.1	−44.5	−10.9	1,271	1,296	+25
Group 2, 1929	1,028.3	2,431.8	617.7	600.3	−17.4	−2.8	1,229	1,214	−15
Soft dough:									
Group 3, 1928	1,028.3	1,706.0	438.6	431.4	−7.2	−1.6	1,221	1,243	+22
Group 3, 1929	1,072.4	2,394.4	598.1	591.5	−6.6	−1.1	1,304	1,277	−27
Cut every 30 days:									
Group 5, 1929	1,083.6	2,711.7	696.8	664.3	−32.5	−4.7	1,290	1,291	+1
Alfalfa check:									
Group 4, 1928	1,050.0	1,726.1	444.2	436.7	−7.5	−1.7	1,239	1,303	+64
Group 4, 1929	1,142.5	2,889.3	703.8	729.5	+25.7	+3.6	1,370	1,385	+15

[1] Average of 7-day preliminary period.

PALATABILITY AND CONSUMPTION OF THE HAYS CUT AT DIFFERENT STAGES OF GROWTH

An analysis of Table 6 shows clearly that the Sudan-grass hay cut at the first-heads-out stage was more palatable and more of it was consumed with less refused than of hay cut at later stages. Only 591 pounds of the first-heads-out hay was refused, in spite of the fact that this group of cows was offered 3,000 pounds of this hay as compared to the 2,490 pounds of full-head and soft-dough hay that was offered to groups 2 and 3, respectively. However, the cows in group 1 were considerably heavier in body weight than those in the other groups and were a little older. In 1929, however, when the amount of hay fed was approximately the same for groups 1, 2, and 3, only 15.8 per cent of the first-heads-out hay was refused as compared with 20.4 per cent of the full-head hay and 18.3 per cent of the soft-dough-stage hay. This difference in the amounts of hay refused in the two years is probably due to the fact that the later cuttings of the hay fed in 1929 were more immature than the first cuttings only

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that were fed in 1928. During the 1929 feeding trial, more of the first-heads-out hay was consumed than of the 30-day hay and less was refused. This was rather unexpected, and brings out the fact that there was probably little difference in the palatability of these two hays. The two cuttings of first-heads-out hay fed in 1929 represented approximately 45 days' growth. In other words, the 12 to 15 days' difference in growth between the first-heads-out and 30-day hay under the climatic conditions that prevailed in 1929 had but little effect on the palatability of the two stages of hay.

Another interesting point in both years' results is the fact that more of the first-heads-out hay was consumed per cow per day than of any of the other hay fed, including alfalfa. The hay consumption was heavier in all groups in 1929, probably because the hay was of better quality and the cows were producing more milk than in 1928. Another reason is that the cows in 1929 were fed some second-cutting hay, which in the full-head and soft-dough stages was higher in protein and lower in crude fiber than that from the first cutting. Only first-cutting hay of the three respective stages was fed in 1928, and this hay was rather coarse and stemmy, owing to heavy rainfall in May and June. There was but little difference in the hay consumption per cow per day for all of the groups in 1929.

Table 7 shows these consumption figures applied to the yields of hay for both years.

TABLE 7.—*Yields of edible Sudan-grass hay per acre when cut at different stages of maturity, 1928 and 1929*

Stage of cutting and year	Yield per acre [1]	Amount refused by cows	Yield of edible hay per acre
	Pounds	*Per cent*	*Pounds*
First heads out:			
1928	3,723	19.7	2,990
1929	5,172	15.8	4,355
Full head:			
1928	3,911	34.0	2,581
1929	4,840	20.4	3,853
Soft dough:			
1928	3,554	30.2	2,481
1929	5,131	18.3	4,192
Cut every 30 days:			
1929	3,043	16.5	2,541

[1] Air-dry basis.

MILK YIELDS DURING THE EXPERIMENTS

The decline in milk production over the 28-day periods (the first 7 days compared with the last 7 days) was considerably greater in all groups in 1928 than in 1929. (Table 6.) This was due partly to the fact that in 1928 the cows averaged 68 days longer in lactation at the beginning of the trial than did the cows in 1929.

It is rather difficult to interpret the greater decline in milk of group 1, fed first-heads-out hay in 1928 as compared with group 3, fed the soft-dough-stage hay. Group 1 consumed more hay, and the hay was of better quality, as shown by the analyses, than was that fed to group 3. Then too, group 1 consumed approximately 20 pounds more grain and 144 pounds more kafir silage than did group 3. However, the grain consumed according to milk produced was at a slightly higher ratio for group 1 than for group 3. Group 1 had averaged 158 days in lactation when the trial started, while group 3 had averaged 232 days. A study of the records of consumption and

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production of the individual animals does not offer sufficient reason for the greater decline. A comparison of the nutrients consumed with the amounts required, as shown in Table 8, indicates that all groups for both years were fed in excess of their requirements. In 1928 the cows in group 1 consumed approximately 20 per cent of total digestible nutrients in excess of their requirements, while groups 2 and 3 consumed only 1.4 per cent and 6.2 per cent, respectively, in excess of their requirements. Perhaps the real reason for the lower rate of decline from the first period to the fourth period of the trial is that group 3 on soft-dough hay suffered such a great decline between the preliminary 7-day period and the first 7-day period of the feeding trial. The comparative percentage declines computed in one case from the production in the first 7-day period to the last 7-day period of the feeding trial, and in the other case from the production during the 7-day preliminary period to that of the last 7-day period of the trial (Table 9), shows that in both 1928 and 1929 the cows on soft-dough hay were second only to the cows fed the full-head hay in the greatest percentage decline when measured from the production during the preliminary 7-day period.

TABLE 8.—*Nutrients (pounds) consumed in feed and required for maintenance and production by groups of cows fed Sudan-grass hay cut at various stages of maturity, during 28-day feeding period, 1928 and 1929*

Stage of cutting and year	Feed consumed during 28 days			Digestible nutrients consumed in—				Average body weight
	Hay	Grain	Silage	Hay	Grain	Silage	Total	
First heads out:								
1928	2,409	380.8	1,172	1,354	273	205	1,832	1,404
1929	2,807	562.8	1,131	1,508	403	198	2,109	1,340
Full head:								
1928	1,642	324.1	1,064	945	232	186	1,363	1,283
1929	2,626	503.0	1,028	1,423	360	180	1,963	1,221
Soft dough:								
1928	1,737	360.5	1,028	1,010	258	180	1,448	1,232
1929	2,693	491.4	1,072	1,351	352	188	1,891	1,290
Cut every 30 days:								
1929	2,726	574.4	1,083	1,361	392	189	1,942	1,290
Alfalfa check:								
1928	2,288	347.9	1,050	1,288	249	183	1,720	1,271
1929	2,747	568.4	1,142	1,542	407	200	2,149	1,377

Stage of cutting and year	Total milk production	Digestible nutrients required			Excess of digestible nutrients consumed above requirements		Digestible nutrients consumed obtained from hay (per cent)
		For maintenance [1]	For production	Total	During period	Per cow per day	
First heads out:							
1928	1,862	935	594	1,529	303	3.6	74
1929	2,806	891	895	1,786	323	3.8	71
Full head:							
1928	1,536	855	489	1,344	19	.2	69
1929	2,431	811	775	1,586	377	4.5	73
Soft dough:							
1928	1,706	819	544	1,363	85	1.0	69
1929	2,394	858	763	1,621	270	3.2	71
Cut every 30 days:							
1929	2,712	858	865	1,723	219	2.6	70
Alfalfa check:							
1928	1,726	846	552	1,398	322	3.8	75
1929	2,889	918	921	1,839	310	3.7	72

[1] Savage feeding standard.

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It is probable, too, that the limited number of cows in each group and the short duration of the feeding trials (28 days) did not allow sufficient time to bring about the greater difference in the comparative feeding value of these hays that was to be expected from the difference in composition.

FEED CONSUMED AND MILK PRODUCED, BY 7-DAY PERIODS

The amounts of the various feeds consumed and the amount of milk produced by the various groups, by 7-day periods, are shown in Table 9. The feed records for the week previous to the preliminary 7-day periods are also shown.

TABLE 9.—*Feed consumption and milk production (pounds) by 7-day periods by groups of cows fed Sudan-grass hays cut at different stages of maturity, and alfalfa hay, 1928 and 1929*

Stage of cutting, group, and year	Feed consumed			Milk produced
	Grain	Hay	Silage	
WEEK BEFORE PRELIMINARY PERIOD				
First heads out:				
Group 1, 1928	141.0	287	804	-------
Group 1, 1929	128.8	276	812	-------
Full head:				
Group 2, 1928	149.0	270	782	-------
Group 2, 1929	149.0	252	756	-------
Soft dough:				
Group 3, 1928	154.0	261	777	-------
Group 3, 1929	141.4	259	791	-------
Cut every 30 days:				
Group 5, 1929	148.4	266	798	-------
Alfalfa (check):				
Group 4, 1928	136.0	[1] 262	726	-------
Group 4, 1929	146.3	[2] 277	291	721.0
PRELIMINARY 7-DAY PERIOD				
First heads out:				
Group 1, 1928	147.0	288	829	528.7
Group 1, 1929	138.0	266	812	728.3
Full head:				
Group 2, 1928	151.0	270	812	462.1
Group 2, 1929	149.0	252	756	711.6
Soft dough:				
Group 3, 1928	154.0	261	777	531.3
Group 3, 1929	141.4	259	791	678.8
Cut every 30 days:				
Group 5, 1929	148.4	266	798	709.6
Alfalfa (check):				
Group 4, 1928	140.0	[1] 263	784	485.8
Group 4, 1929	185.5	288	861	701.0
FIRST 7-DAY PERIOD				
First heads out:				
Group 1, 1928	105.0	547	293	490.2
Group 1, 1929	144.2	693	283	701.9
Full head:				
Group 2, 1928	92.4	371	266	409.6
Group 2, 1929	141.4	613	258	617.7
Soft dough:				
Group 3, 1928	109.0	398	256	438.6
Group 3, 1929	134.4	650	273	598.1
Cut every 30 days:				
Group 5, 1929	140.7	698	271	696.8
Alfalfa (check):				
Group 4, 1928	93.1	527	260	444.2
Group 4, 1929	139.3	667	288	703.8
SECOND 7-DAY PERIOD				
First heads out:				
Group 1, 1928	97.3	624	291	467.9
Group 1, 1929	139.3	713	283	702.8
Full head:				
Group 2, 1928	81.2	436	262	385.8
Group 2, 1929	121.5	654	257	605.0
Soft dough:				
Group 3, 1928	86.8	432	251	416.8
Group 3, 1929	118.3	678	267	600.1
Cut every 30 days:				
Group 5, 1929	138.6	693	274	706.5
Alfalfa (check):				
Group 4, 1928	88.2	604	260	419.8
Group 4, 1929	140.0	700	278	727.3
THIRD 7-DAY PERIOD				
First heads out:				
Group 1, 1928	92.4	606	291	454.6
Group 1, 1929	140.0	705	283	700.4
Full head:				
Group 2, 1928	77.0	389	266	375.5
Group 2, 1929	119.7	668	256	608.8
Soft dough:				
Group 3, 1928	81.9	434	258	419.2
Group 3, 1929	119.0	664	265	604.7
Cut every 30 days:				
Group 5, 1929	140.0	627	271	644.1
Alfalfa (check):				
Group 4, 1928	83.8	605	262	425.4
Group 4, 1929	144.2	690	286	728.7
FOURTH 7-DAY PERIOD				
First heads out:				
Group 1, 1928	86.1	631	298	449.2
Group 1, 1929	139.3	696	284	701.4
Full head:				
Group 2, 1928	73.5	446	270	365.1
Group 2, 1929	120.4	691	258	600.3
Soft dough:				
Group 3, 1928	83.3	473	263	431.4
Group 3, 1929	119.7	701	267	591.5
Cut every 30 days:				
Group 5, 1929	128.1	708	268.1	664.3
Alfalfa (check):				
Group 4, 1928	83.3	605	268	436.7
Group 4, 1929	144.9	690	291	729.5

[1] This group was fed Sudan-grass hay during this 7-day period.
[2] Sudan-grass hay fed during this period.

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In 1928 there was a gradual increase in hay consumption for all groups from the first to the last 7-day period of the 28-day trial. Groups 1 and 2 for some unknown reason fell off rather heavily in hay consumption during the third period, while groups 3 and 4 maintained their consumption. During the fourth and last 7-day period groups 1, 2, and 3 increased materially the amount of hay consumed, while that consumed by group 4 remained the same. Groups 1 and 2 declined steadily in milk production from the first to the last period. All four groups showed a decided drop in production during the second period, but groups 3 and 4 increased their production for the last two periods. The cows in all groups were fed grain at a higher rate during the preliminary 7-day period than they were during the feeding trial. The rate of grain to milk produced was 1 to 3.4 during the preliminary period, while the rate was decreased to 1 pound of grain to 4.5 pounds of milk produced for the first period. The amount of silage fed was also decreased from an average of 26.7 pounds per cow per day to approximately 10 pounds per cow a day. The amount of hay consumed increased materially between the two periods. Such an abrupt change in the ration resulted in lowered production. This was probably the reason for the heavy decrease by all groups during the first 7-day period.

For 1929 the rate of grain feeding for the preliminary period was approximately the same as for the first regular 7-day period, namely, 1 to 4.7. There was an abrupt change in the rate of hay and silage feeding. All of the groups except group 2 on full-head hay produced more milk in the second 7-day period than in the first 7-day period. The cows in 1929 consumed much greater amounts of hay than the cows in 1928. The groups on first-heads-out and alfalfa hay consumed 16.6 and 17.3 per cent more hay respectively during the feeding periods in 1929 than in 1928. The large increases in consumption, however, were in the full-head and soft-dough hay groups, which were 60 and 55 per cent greater in 1929 than in 1928. These great increases were due in part to the fact that the cows in 1929 were fed some hay from all cuttings, whereas in 1928 hay from the first cuttings only was fed. The full-head and the soft-dough hay from the second cuttings in 1929 were higher in protein and lower in crude fiber than the hay from the first cuttings. This probably accounts for the lower decline in milk yields in 1929. Then, too, the cows fed the full-head and soft-dough-stage hay in 1929 consumed a greater margin of total digestible nutrients over requirements than did the cows in 1928.

FEEDING SUDAN-GRASS SILAGE IN COMPARISON WITH SUDAN-GRASS HAY FOR MILK PRODUCTION

FEEDING EXPERIMENTS WITH SILAGE, AND WITH HAY AND SILAGE, MADE AT FULL-HEAD STAGE

Comparative feeding data were secured for one year (1929) on two groups of cows of which one group was fed Sudan-grass silage made at the full-head stage and the other group was fed Sudan-grass hay and Sudan-grass silage made at the full-head stage. These two groups of three cows each were fed for a period of 42 days under the same conditions as were those which were fed the Sudan-grass hay at the three stages of maturity. A grain ration of the same composition as that used in the previous experiments was fed at the rate of 1 pound of grain to 5 pounds of milk produced daily.

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The hay was cut at the full-head stage in 1929 and represented a portion of the hay discussed in the previous experiment. The silage was cut at the same stage and at the same time as the full-head hay and was immediately placed in a pit silo. Some wilting took place before ensiling. The silage was of excellent quality and was very palatable.

In the case of the silage-fed group, care was taken to feed the cows only the amount they would readily clean up. For the group fed hay and silage, an attempt was made to feed both ad libitum, but it is possible that in doing this the hay may have been limited to a small extent. However, the percentage of hay refused by this group (23.4 per cent) is not greatly out of line with the percentage of fully headed hay refused (20.4 per cent) by the cows in the previous 28-day hay feeding trial.

Table 10 is a summary of this feeding trial.

TABLE 10.—*Consumption and feeding value of full-head Sudan-grass silage compared with Sudan-grass hay and Sudan-grass silage over 42-day feeding period, 1929*

Material fed	Average age of cows	Stage of lactation at start	Average body weight per cow at start	Average loss in body weight for 42 days	Average daily milk yield at start	Milk produced		Decline in milk yield
						During 42 days	Per cow per day	
	Years	*Days*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Per cent*
Silage	5½	132	1,227	36	34.6	3,921.4	31.1	14.7
Hay and silage	5½	129	1,260	32	36.6	3,969.3	31.5	17.2

Material fed	Roughage consumed				Roughage refused		Dry matter consumed per cow per day in roughage[1]	Grain consumed during 42 days
	Silage		Hay		Silage	Hay		
	In 42 days	Per cow per day	In 42 days	Per cow per day				
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Pounds*	*Pounds*
Silage	11,316	89.8	--------	--------	0	--------	29.6	805.0
Hay and silage	9,649	76.5	1,313	10.4	.1	23.4	34.6	821.4

[1] Silage and hay averaged 33 and 90 per cent dry matter, respectively.

These two groups of cows were evenly balanced in age, stage of lactation, and milk production at the start. The daily consumption of dry matter per cow was approximately 5 pounds greater for the hay plus silage group.

Table 11 shows the average daily consumption and milk production per cow for the six 7-day periods. The group fed silage alone started with a heavy consumption but apparently lost their appetite for such a large quantity before the third 7-day period. Their consumption gradually diminished until the end of the period. There were apparently no bad effects on the health of this group of cows, as they appeared normal in every way.

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TABLE 11.—*Average daily roughage consumption and average daily milk production per cow by 7-day periods when fed full-head Sudan-grass silage, and Sudan-grass hay and silage, 1929*

7-day period	Cows fed silage		Cows fed hay and silage		
	Silage consumed	Milk produced	Hay consumed	Silage consumed	Milk produced
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Preliminary		34.6			36.6
First	104.1	33.3	11.5	68.5	34.6
Second	104.2	33.1	10.2	78.0	33.7
Third	88.8	32.2	10.1	81.1	32.2
Fourth	91.6	30.5	10.1	85.2	30.6
Fifth	77.7	29.3	10.0	76.6	29.1
Sixth	73.0	28.4	10.5	69.7	28.7
Average	89.8	31.1	10.4	76.5	31.5

As the experiment with Sudan-grass hay cut at different stages in 1929 included a group of cows fed full-head hay and kafir silage at the rate of 1 pound per 100 pounds of live weight, their feed consumption and milk yield is comparable with the group fed silage made from full-head Sudan grass as the only roughage and the group fed hay and silage made from full-head Sudan grass. The average consumption of dry matter in the roughage and percentage decline in milk yield of these groups is given in Table 12.

TABLE 12.—*Average dry-matter consumption and average decline in milk yield by 7-day periods for cows on full-head Sudan-grass hay and kafir silage, full-head Sudan-grass silage, and full-head Sudan-grass hay and Sudan-grass silage, 1929*

7-day period	Cows on Sudan-grass hay and kafir silage		Cows fed Sudan-grass silage		Cows fed Sudan-grass hay and Sudan-grass silage	
	Dry matter in roughage	Milk decline	Dry matter in roughage	Milk decline	Dry matter in roughage	Milk decline
	Pounds	*Per cent*	*Pounds*	*Per cent*	*Pounds*	*Per cent*
First	212	13.2	240	3.7	230	5.4
Second	224	2.1	240	0.6	244	2.6
Third	228	[1] 0.6	205	3.0	251	4.4
Fourth	235	1.4	211	5.2	260	5.0
Fifth			179	3.9	240	4.9
Sixth			169	3.0	227	1.3

[1] Increase.

The feeding trial for the group on Sudan-grass hay and kafir silage lasted only 28 days, while for the groups on Sudan-grass silage, and Sudan-grass hay and silage the feeding trials lasted 42 days. The consumption of dry matter in the form of roughage, of the group on hay and kafir silage, increased steadily with each 7-day period, while the percentage decline in milk yield was much lower than for the other two groups except in the first and second 7-day periods following the preliminary period.

The consumption of dry matter in the roughage part of the ration for the group on Sudan-grass hay and Sudan-grass silage also increased

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steadily up to the last two periods, when there was a decrease. The decline in milk yield was steady for each 7-day period, except for the second and sixth periods. The cows in this group consumed 73 per cent of the total dry matter in the roughage ration, in the form of Sudan-grass silage, while the cows receiving Sudan-grass hay and kafir silage consumed only 13 per cent of the dry matter in the roughage part of the ration in the form of silage.

The consumption of dry matter in the group on Sudan-grass silage alone was less than that for the other two groups except for the first and second 7-day periods. There was a decrease in consumption of dry matter throughout the experiment. The decline in milk flow was rather uniform except for the second period.

Comparing the declines in milk yield for the three groups for the duration of the experiment, that is, from the yield for the 7-day preliminary period to the yield for the last 7-day period of the feeding trial, it is seen that the decline for the group on hay and kafir silage is 16 per cent; that for the group on Sudan-grass silage alone the decline is 11.8 per cent to the end of the fourth period (when the trial on hay and kafir silage ended) and 17.9 per cent to the end of the sixth period; and that for the group on Sudan-grass hay and Sudan-grass silage the decline is 16.4 per cent to the end of the fourth 7-day period and 21.6 per cent to the end of the sixth period. The decline for the cows on silage seems to be at a lower rate, in spite of the fact that their consumption of dry matter was less than that of the other groups. This is in agreement with the results of an experiment conducted by this bureau [6] comparing the value for milk production of hay and silage made from pasture herbage. The decline for the group fed hay and kafir silage and that for the group fed hay and Sudan-grass silage is approximately the same. From these results it appears that, pound for pound of dry matter, the silage was somewhat more efficient in stimulating milk flow than was field-cured hay made from Sudan grass of the same stage of maturity.

FEEDING EXPERIMENTS WITH SILAGE AND WITH HAY, MADE AT THE FIRST-HEADS-OUT STAGE

Since the experiments comparing the value of hay made from Sudan grass cut at three different stages of maturity showed that the hay cut when first heads appeared was more efficient in maintaining milk yield than was the hay cut at later stages of maturity, an experiment was conducted in 1931 to determine the relative efficiency in maintaining milk production, of hay and silage made from Sudan grass cut when the first heads were appearing.

The silage was made from the first of three cuttings. Some water was added to the grass as it went into the silo. The silage made from Sudan grass in 1929 kept well, and there was little spoilage, but unfortunately the 1931 silage did not keep well. It was warm to the touch of the hand throughout the 42-day feeding trial and spoiled rapidly when exposed to the air. It was necessary to separate the moldy silage from the good, by hand, as it was removed from the silo.

Two groups of three cows each were used in the experiment. Both groups were fed a grain mixture at the rate of 1 pound to each 5 pounds of milk produced. The grain mixture consisted of 4 parts ground wheat, 4 parts wheat bran, 1 part cottonseed meal, and 1 part

[6] Unpublished data.

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linseed meal. The cows in one group received hay made from Sudan grass cut at the first-heads-out stage, ad libitum. No other hay or silage was fed. The cows in the other group received silage made from Sudan grass cut at the same stage of maturity, ad libitum. No other silage or hay was fed. The cows in the hay-fed group averaged 143 days in lactation and 1,355 pounds in body weight, and the cows in the silage-fed group averaged 139 days in lactation and 1,368 pounds in body weight.

The total feed consumption, milk yield, and decline in milk yield by 7-day periods is shown in Table 13.

TABLE 13.—*Consumption of hay and silage made from Sudan grass cut at the first-heads-out stage and the milk yield by 7-day periods, 1931*

7-day period	Total feed consumed			Total milk yield	Decline (−) or gain (+) in milk production over preceding period	
	Hay	Silage	Grain			
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Per cent*
HAY GROUP						
Preliminary	(1)	[2] 868	225.4	849.7		
First	808	None.	169.4	840.8	−8.9	−1.04
Second	707	None.	167.3	851.6	+10.8	+1.28
Third	693	None.	168.7	844.9	−6.7	−.78
Fourth	722	None.	168.7	819.5	−25.4	−3.00
Fifth	715	None.	162.4	803.6	−15.9	−1.94
Sixth	702	None.	159.6	785.2	−18.4	−2.28
SILAGE GROUP						
Preliminary	(1)	[2] 882	224.0	826.3		
First	None.	1,675	167.3	754.6	−71.7	−8.67
Second	None.	1,665	150.5	824.1	+69.5	+9.21
Third	None.	1,410	163.1	827.8	+3.7	+.44
Fourth	None.	1,540	164.5	814.9	−12.9	−1.55
Fifth	None.	1,675	161.7	790.4	−24.5	−3.00
Sixth	None.	1,564	157.5	772.6	−17.8	−2.25

[1] Hay was fed ad libitum, but not weighed.
[2] Kafir silage.

The cows in the hay group were fed the hay at an average rate of 44.7 pounds per cow per day and consumed 34.5 pounds per day, the refusal averaging 10.2 pounds or 22.8 per cent. The cows on silage consumed the silage at an average rate of 75.6 pounds per cow per day, which is considerably less than the average consumption of 89.8 pounds of Sudan-grass silage in 1929. This difference is no doubt due to spoilage of the 1931 silage. The hay consumption is a little greater than for the same kind of hay in 1929. The consumption of hay, and also of silage, would have been greater had no grain been fed.

The consumption of hay by 7-day periods by the cows in the hay group was greatest in the first period, averaging 38.5 pounds per cow per day. The average consumption dropped to 33.6 pounds per day in the second period, and during the remainder of the experiment varied less than a pound from that figure during any 7-day period.

The consumption of silage by 7-day periods by the cows in group 2, was approximately the same in the first and second periods, averaging 79.8 and 79.3 pounds per cow per day. In the third period the average consumption dropped to 67.1 pounds, probably on account of a difference in the quality of the silage fed. In the fourth period the con-

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sumption increased to 73.3 pounds, and in the fifth period to 79.8 pounds, but in the sixth period dropped back to an average of 74.5 pounds per cow per day. There was not the steady decline in consumption of silage in this experiment that was experienced with the silage made from Sudan grass when fully headed, in 1929. The percentages of dry matter in the hay and silage fed in this experiment had not been determined when this was written. If the percentages of dry matter that were found in the 1929 hay and silage are applied to the quantities of hay and silage consumed in 1931, the cows on the silage ration consumed 24.1 per cent less dry matter than the hay-fed cows in the first 7-day period and 18.4 per cent less dry matter in the last 7-day period. Since the quantity of grain fed both groups is practically the same, this figure represents the difference in dry-matter consumption in the entire ration, provided the error in using the 1929 percentages of dry matter is not too great. The difference in dry-matter consumption in the last 7-day period in the 1929 experiment between the silage-fed group and the group fed both hay and silage was 25.5 per cent in favor of the hay and silage fed group.

With this greater dry-matter consumption of the cows receiving hay, it might be expected that these cows would decline in milk flow at a slower rate than the silage-fed cows. Such was not the case, however. A comparison of the milk yield in the preliminary 7-day period with the yield in the last 7-day period shows a decline of 7.59 per cent for the hay-fed cows and 6.49 per cent for the silage-fed cows. The milk decline of the cows fed full-head Sudan-grass silage in the 1929 experiment was 18 per cent, and the decline for the cows in that experiment that were fed both hay and silage was 21 per cent. It appears, therefore, that the silage made from Sudan grass cut at the first-heads-out stage was more efficient for milk production than the silage made from grass cut when fully headed, even though the former was not of the best quality. Also, as in the 1929 experiment, and as in an experiment with hay and silage made from pasture herbage at the Huntley, Mont., station,[7] the dry matter of the Sudan-grass silage was, pound for pound, more valuable for milk production than was that in the field-cured hay cut from grass at the same stage of maturity.

The decline in milk yield of the cows fed Sudan-grass hay cut at the first-heads-out stage in 1931, from the preliminary 7-day period to the fourth 7-day period of the experiment, which compares with the length of the feeding trials in 1929, was 3.5 per cent. The decline for the cows fed Sudan-grass hay cut at this same stage of maturity in 1929 but with kafir silage in addition, was 3.7 per cent. This suggests that the addition of the kafir silage to the ration, fed at the rate of 1 pound of silage to each 100 pounds of live weight, was of no particular value. The decline for the cows fed fully headed hay with kafir silage, in 1929, for this same period of time, was 15.6 per cent. This emphasizes again, the superior value for milk production of Sudan-grass hay cut at an immature stage of development.

In view of the fact that both groups of cows in 1931 were fed during the preliminary seven days a ration of Sudan-grass hay ad libitum, and kafir silage at the rate of 41 and 42 pounds per day per cow, respectively, and a grain mixture at the rate of 1 pound to each 3.7

[7] Unpublished data.

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pounds of milk produced, and that during the experimental periods they were fed hay alone or silage alone, and the grain mixture at the rate of 1 pound to each 5 pounds of milk produced, the return to the same level of production during the second and third 7-day periods as that of the preliminary period is rather remarkable. With no knowledge of any environmental factors that might have caused a depression of the milk yield during this preliminary period, this return to the same level of production in the second and third weeks thereafter, accompanied by a decreased grain consumption, suggests that the dry matter consumed in the hay and the silage during the experimental feeding period was much superior for milk production to that fed in the hay and silage during the preliminary period. It is again suggested that where the dry matter in the hay and in the silage is of equivalent value for milk production there is probably no advantage in feeding hay with silage or silage with hay. This is borne out to a certain extent by the results of an experiment conducted at the Beltsville (Md.) Experiment Station comparing the value of beet pulp when soaked with water and when fed in the dry state.[8] The dry pulp proved to be as palatable as the wet, and the production of milk was as great in one case as in the other.

The cows were weighed on the last two days of each 7-day period. The net gains or losses in weight are calculated by comparing the average weight of the group for the last two days of the 7-day preliminary period, with the average weight for the last two days of the sixth 7-day period. The 3 cows in the hay group had a net loss of 28 pounds, 1 cow lost 35 pounds, 1 cow lost 55 pounds, and the third cow gained 62 pounds. The 3 cows in the silage group had a net loss of 44 pounds, 1 cow lost 33 pounds, 1 lost 18 pounds, and the third cow gained 7 pounds.

The difference in loss between the two groups is too small to be significant.

VALUE OF SUDAN-GRASS PASTURE FOR MILK PRODUCTION

An experiment was started in 1928 to determine the value of Sudan-grass pasture for carrying capacity and milk production. Results of four seasons' work (1928 to 1931, inclusive) are here reported.

Two and one-half acres were seeded each year at the rate of 12 pounds per acre. As soon as the grass had made sufficient growth, grazing with milking cows was started. Care was taken to select only cows that were normal in lactation. Cows were added to the plots or taken off according to the growth of the grass. At times, because of favorable conditions, as many as six cows were on the plots, while at times of poor growth conditions, no cows were grazed for considerable periods of time. Accurate records were kept of the days that cows were grazed, their milk and butterfat production during the days they were on pasture, their body weight, and the grain or other feed they consumed while on pasture.

The cows were of similar breeding, and conditions other than pasture were kept as nearly comparable as possible. They were milked twice daily except in 1931.

Table 14 shows the essential data for the four years 1928 to 1931.

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[8] WOODWARD, T. E., SHEPHERD, J. B., and GRAVES, R. R. FEEDING AND MANAGEMENT INVESTIGATIONS AT THE UNITED STATES DAIRY EXPERIMENT STATION AT BELTSVILLE, MD., 1930 REPORT. U. S. Dept. Agr. Misc. Pub. 130: 12–14. 1932.

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TABLE 14.—*Carrying capacity and milk and butterfat production of Sudan-grass pasture, 1928–1931*

Year	Date of seeding	Pasture season			Cows grazed on plots	Total cow-days [1] per acre	Supplemental feed per acre		Production per acre		Net gain in body weight per acre
		Opened	Closed	Length			Grain	Silage	Milk	Butter-fat	
				Days	*Days*	*No.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1928	June 1	July 2	Oct. 17	108	76	94.8	689.4	870.4	3,717	105.4	56.8
1929	June 7	July 8	do	102	102	94.8	638.5	None.	4,519	134.1	55.2
1930	May 27	July 1	Sept. 30	92	44	52.8	371.8	None.	2,187	65.1	79.2
1931	June 8	July 9	Oct. 15	99	49	57.6	704.3	None.	2,378	72.7	−1.2
Average				100	68	75.0	601.0	218.0	3,200	94.3	47.5

[1] A cow-day is a 24 hour period, day and night, that one cow grazed.

In 1928 the pasture season lasted for 108 days, but cows were grazed on the plot for only 76 days. Because of long-continued dry weather no cows were grazed on the plot from August 18 to September 18, inclusive. The rainfall for the five months, May to September, inclusive (Table 3), totaled 13.01 inches, of which 11.85 inches fell in May, June, and July. Only 0.35 inch of rain fell in August and 0.81 inch in September.

The pasture season of 1929 began approximately one week later than that of 1928. There were 2.09 inches of rain in August and 4.45 inches in September. This distribution of rainfall resulted in sufficient growth of the Sudan grass to make it possible for a limited number of cows to be grazed throughout the season. The increase in production over that in 1928 was probably due to better grazing caused by the more favorable distribution of rainfall during the pasture season. However, this 2½-acre plot had been seeded to winter rye in the fall of 1927 and grazed during April and May, 1928. It then lay idle during the summer of 1928. This may have been partly responsible for the more favorable production.

In 1930 the grazing season extended over a period of only 92 days, but cows actually grazed only 44 days of this time. From July 25 to September 10 no grazing was available. A study of the rainfall in 1930 (Table 3), gives the reason for the short grazing season. Heavy rains fell in May and early June before the grass was well started. No effective rains came after June 9 until August, when 1.42 inches fell.

In 1931 the Sudan grass was seeded May 29. Heavy rainfall on June 5 (1.9 inches) washed and packed the surface of the soil so that practically none of the seed came through. The plot was reseeded June 8, and a good stand was secured. Grazing started July 9 with four cows, and they were kept on the plot continuously until August 1. Rainfall totaling 0.93 inch during August 1, 2, and 3 had no appreciable effect on the growth of the grass, and it did not recover sufficiently for grazing until September 4. On account of a shortage of suitable animals the cows used to graze the Sudan grass in 1931 were 2-year-old heifers on official test, and they were milked three times per day. In the previous experiments the cows had been milked twice a day. Although grain was fed at a heavier rate in 1931, the rate of milk yield was lower than in 1928 or 1929, and was very little greater than in 1930. The poor grazing season again illustrates the effect of poor distribu-

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tion of rainfall during the pasture season on growth and recovery of Sudan grass after grazing.

The average of the four years' results shows that under conditions prevailing in this locality, approximately 75 cow-days of grazing per acre were obtained. An average production of 3,200 pounds of milk per acre, which contained 94 pounds of butterfat was secured for the four years, when the pasture was supplemented with a grain mixture fed at the average rate of 1 pound to each 5.3 pounds of milk produced.

VALUE OF SUDAN-GRASS PASTURE IN COMPARISON WITH SUDAN-GRASS HAY

In order to obtain a measure of the value of the nutrients in the Sudan-grass pasture the following method, devised by the Bureau of Dairy Industry,[9] was applied:

The total digestible nutrients necessary to maintain the cows at the average body weight for the periods that they grazed and for the milk they produced during those periods were calculated according to the Savage feeding standard. From the required nutrients thus calculated were deducted the nutrients contained in the grain and silage fed while the cows were on the Sudan-grass pasture. The difference was taken as the quantity of nutrients that could be credited to the pasture. By converting this quantity of nutrients into its equivalent of Sudan-grass hay or alfalfa hay, the value of the pasture was figured on a comparative basis with these hay crops. In making these calculations the average daily body weight of the cows by months or for the shorter periods they might have grazed was used. For example, a cow weighed 1,200 pounds on July 1, when she started to graze. She grazed continuously for 23 days, after which she was taken off. Her body weight when she was taken off was 1,220 pounds. Her average daily body weight for the 23 days was considered as 1,210 pounds, the average of the initial and final weights.

It is realized that several chances for error are present in these calculations, aside from the feeding-standard requirements and average analyses used in several cases: (1) The average daily body weight of the animals for the periods of grazing was used, and no attempt was made to calculate specific individual increases or losses in weight other than the average. All cows on Sudan-grass pasture showed a tendency to increase in body weight, except in 1931. This was also true in the hay-feeding experiment in 1928. In 1929, however, the group of cows fed first-heads-out Sudan-grass hay showed a tendency to lose weight. (2) That portion of the hay fed that was not consumed in the feeding trials of 1928 and 1929 is assumed to have contained the same percentage of nutrients as the hay that was consumed. In reality it consisted largely of stems and probably contained less nutrients. The nutrients obtained in the consumed portion of the hay for this reason were probably somewhat higher than the calculations indicate. (3) No effort was made to obtain the yield of aftermath after the grazing ended in the fall. A considerable quantity of heavy stems was left standing on the plots. Probably this would compensate somewhat for the portion of the hay that was refused by cows in the feeding trials. (4) Perhaps the greatest possibility of error in these calculations is that average coefficients of digestibility for Sudan-grass hay as given in Henry and Morrison's

[9] MOSELEY, T. W., STUART, D., and GRAVES, R. R. DAIRY WORK AT THE HUNTLEY FIELD STATION, HUNTLEY, MONT., 1918-1927. U. S. Dept. Agr. Tech. Bul. 116: 3. 1929.

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Feeds and Feeding were used, since it was not possible to conduct digestion trials on the hay cut at different stages of maturity. It is probable that these coefficients of digestibility were obtained from hay made from Sudan grass cut at a more mature stage of development. There is reason to believe that the nutrients in such hay would not be as digestible as the nutrients from hay cut at an immature stage.

The results of these calculations for the four years covered by the grazing work are shown in Table 15.

TABLE 15.—*Calculated yield of total digestible nutrients (pounds) grazed from 1 acre of Sudan-grass pasture and its equivalent value in Sudan-grass hay and in alfalfa hay, 1928–1931*

Year and month	Cow-days of grazing	Digestible nutrients required for—		Total digestible nutrients required	Digestible nutrients in grain consumed	Calculated digestible nutrients credited to pasture	Hay required to furnish total digestible nutrients equivalent to pasture	
		Maintenance	Production				Sudan [1]	Alfalfa
1928								
July	46.4	437.780	518.312	956.092	178.542	777.550		
August	20.8	192.628	217.816	410.444	122.910	287.534		
September	7.2	68.532	81.708	150.240	[2] 85.708	64.532		
October	20.4	193.038	220.094	413.132	[2] 274.656	138.476		
Total	94.8	891.978	1,037.930	1,929.908	661.816	1,268.092	2,256	2,247
1929								
July	39.6	377.118	571.213	948.331	219.010	729.321		
August	29.6	305.830	413.842	719.672	190.958	528.714		
September	12.0	118.212	150.133	268.345	63.169	205.176		
October	13.6	93.328	154.914	248.242	61.928	186.314		
Total	94.8	894.488	1,290.102	2,184.590	535.065	1,649.525	3,071	2,937
1930								
July	28.8	291.612	371.394	663.006	163.615	499.391		
September	24.0	249.988	252.952	502.940	107.536	395.404		
Total	52.8	541.600	624.346	1,165.946	271.151	894.795	1,509	[3] 1,590
1931								
July	36.8	340.050	397.085	737.135	308.250	429.825		
September	8.8	82.755	125.008	207.763	83.054	124.708		
October	12.0	119.601	171.622	291.223	99.814	191.409		
Total	57.6	542.406	693.715	1,236.121	491.118	745.942	[3] 1,357	[3] 1,326

[1] Cut at first-heads-out stage.
[2] 368 pounds of silage was fed in September and 1,808 pounds was fed in October in addition to grain.
[3] Calculated from average content of total digestible nutrients in the hay for 1928 and 1929.

The number of days of grazing secured in the different years, and in the different months of the grazing season of each year, varied greatly according to the amount and distribution of rainfall. The number of cow-days per acre varied from 52.8 in 1930 to 94.8 in 1928 and 1929. The average for the 4 years was 75 cow-days. It will be recalled that the Sudan grass had been seeded on June 1, or as soon after that date as possible. The greatest amount of grazing in all four years was secured in July with a variation of from 28.8 cow-days in 1930 to 46.4 cow-days in 1928. In 1930 and 1931 there was no grazing in August, but the grazing was sufficiently good in that month during 1928 and 1929 to rank August third for the 4-year period in amount of grazing secured during the months included in

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the grazing season. September provided some grazing in each of the 4 years, and October in 3 of the 4 years, but the average for the 4 years was only 11.5 cow-days, which is the lowest average for any of the 4 months. In order to provide continuous pasturage during these four months for a herd of cows, it would be necessary to provide a sufficient acreage per cow to permit a rotation from field to field, and even then it is doubtful whether continuous grazing could be secured in a year like 1930. Theoretically, it would have required 2.27 acres per cow to furnish continuous grazing for four months in 1930, while in 1928 and 1929 only 1.26 acres would have been required. The fact that more than half the pasturage is secured in

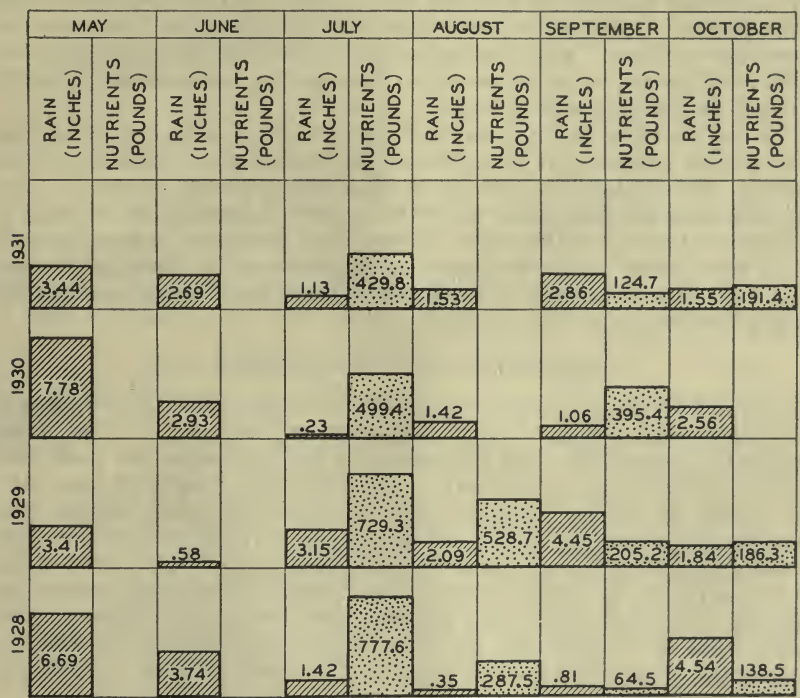

FIGURE 2.—Distribution of rainfall (inches) and calculated yield of total digestible nutrients (pounds per acre) of Sudan-grass pasture by months, in grazing experiments, 1928–1931

July, while the other half is fairly evenly distributed over August, September, and October, makes it difficult to secure continuous grazing even when a generous acreage per cow is allowed and rotation is practiced.

The amount of total digestible nutrients provided by an acre of Sudan-grass pasture corresponds very closely to the number of cow-days for the different years and for the different months. The variation in yields of total digestible nutrients by years and months furnished by the pasture is shown in Figure 2, together with the rainfall. The average yield of total digestible nutrients credited to the Sudan-grass pasture for the four years is 1,139.6 pounds per acre. The 4-year average also shows that 53 per cent of this total amount was secured in July, 17.9 per cent in August, 17.3 per cent in September, and 11.3 per cent in October. The average amount of total digestible

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nutrients (1,139. 6 pounds) secured from an acre of Sudan-grass pasture could be secured in 2,048 pounds of Sudan-grass hay, cut in the first-heads-out stage. As the average acre yields of air-dry hay cut at this stage of maturity for the four years was 3,667 pounds, it required only 0.56 acre of hay to produce as much total digestible nutrients as 1 acre of pasture furnished. However, there is an error in this calculation due to the fact that in the 1928 and 1929 feeding experiments an average of 17.7 per cent of the hay cut at first-heads-out stage was refused. This refusal was the coarser, stemmy portion of the hay that would be lower in nutritive value than that consumed. No analysis of the refused hay is available. If the 3,667 pounds of hay produced per acre is reduced by 17.7 per cent to conform to the edible portion, 3,018 pounds of edible hay was produced per acre for the 4-year average. On this basis, 0.67 acre of Sudan-grass hay cut in the first-heads-out stage produced the equivalent in edible nutrients of 1 acre of Sudan-grass pasture.

The results show clearly, however, that there is a close relationship between the production of nutrients in Sudan-grass pasture or hay and the distribution of rainfall during the growing months. The data also indicate that under conditions that obtained in the vicinity of Woodward, Okla., for the years 1928 to 1931, inclusive, approximately 33 per cent more edible nutrients were grown in the form of Sudan-grass hay cut at the first-heads-out stage than were secured by grazing Sudan grass with Holstein cows.

SUMMARY AND CONCLUSIONS

Data are presented giving the results of three years' experiments at the Woodward (Okla.) Dairy Experiment Station, on the yield, chemical composition, and comparative feeding value for milk production of Sudan-grass hay cut at four different stages of maturity. The yields of air-dry hay per acre at these different stages were surprisingly close by years, averaging 4,033 pounds for the first-heads-out stage, 3,925 pounds for the full-head stage, and 3,922 pounds for the soft-dough stage for the three years. The yield of hay cut every 30 days was only 3,043 pounds per acre in 1929, due to poor distribution of rainfall, but in 1930, it was practically the same as that for the other more mature stages. The yield is largely dependent upon the distribution of rainfall during the growing months. If sufficient moisture is available, as in 1929, three cuttings may be obtained from the first-heads-out stage, two cuttings from the full-head and soft-dough stages, and four cuttings from the 30-day-stage hay. If the rainfall during the growing months is poorly distributed, as in 1928, only one cutting of the typical stages as measured by head formation can be secured.

The chemical composition of Sudan-grass hay in general is closely correlated to the maturity of the plants when cut, and to a certain extent follows the number of days of growth. However, the distribution of rainfall (as it affects the growth of the plants) has considerable effect on the chemical composition. The average crude-protein content of the hays in the first cuttings only was 11.8 per cent for first-heads-out stage, 9.1 per cent for the full-head stage, 7.2 per cent for the soft-dough stage, and 13.5 per cent for that cut every 30 days. As the number of days of growth increased the percentages of protein and fat were depressed. In these experiments, the per-

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centage of crude fiber showed a slight tendency to increase as the number of days of growth increased. The percentage of nitrogen-free extract increased steadily as the number of days of growth increased.

The yield of crude protein per acre, based on an average of the three years' results, was 403.6 pounds when the hay was cut at the first-heads-out stage, as compared to yields of 317.8 and 284.7 pounds when the hay was cut at the full-head and soft-dough stages, respectively, or an advantage of 27 and 42 per cent, respectively, in favor of the first-heads-out hay. It would require 1.27 acres of hay cut at the full-head stage and 1.42 acres cut at the soft-dough stage to yield as much crude protein as 1 acre cut at the first-heads-out stage. The hay cut every 30 days yielded an average of 363.6 pounds of crude protein per acre, for the two years' experiments with that stage.

In view of the slightly superior yield of air-dry hay per acre, higher crude-protein content, and much higher yield of crude protein per acre, the data show conclusively that Sudan-grass hay should be cut at the first-heads-out stage. However, there is some evidence—the higher crude-protein content of the 30-day-stage hay—to indicate that if rainfall distribution and other factors are such as to promote rapid recovery and growth so as not to lower the yield, a somewhat earlier stage of cutting Sudan-grass hay than the first-heads-out stage would be desirable from the feeding standpoint.

The superiority in chemical composition of the hay cut at the first-heads-out stage was borne out in the feeding trials with cows fed hay cut at the different stages. Considerably more of the first-heads-out hay was consumed than of the other stages, and less was refused. In fact, more of the first-heads-out hay was consumed than of first-class alfalfa, but more was refused. An average of the two years' feeding experiments shows that when approximately the same total amounts of hay were fed to the different groups of cows, they refused 17.7 per cent of the first-heads-out hay, 27 per cent of the full-head hay, and 24.3 per cent of the soft-dough hay. Apparently there was little difference in palatability of the hays cut at the two later stages. The higher palatability of the first-heads-out hay, however, increases materially the amount of edible air-dry hay and nutrients produced per acre when Sudan-grass hay is cut at that stage.

The first-heads-out Sudan-grass hay was superior to the hay cut at later stages of maturity in maintaining milk yield.

Results of two years' experiments in feeding Sudan-grass hay and Sudan-grass silage, cut in one year at the full-head stage, and in the other year at the first-heads-out stage, are reported. Cows fed full-head Sudan-grass hay and Sudan-grass silage in 1929 consumed a daily average of 10.4 pounds of hay and 76.5 pounds of silage containing 34.6 pounds of dry matter during the 42-day feeding period. Cows on full-head Sudan-grass silage alone consumed a daily average of 89.8 pounds containing 29.6 pounds of dry matter. The decline in milk production was 17.2 per cent for the former group and 14.7 per cent for the latter.

Cows fed first-heads-out Sudan-grass hay in 1931 consumed 34.5 pounds per cow a day, containing 31.1 pounds of dry matter. Their decline in milk production over the 42-day period was 9.4 per cent. Cows fed Sudan-grass silage cut at the first-heads-out stage consumed a daily average of 75.6 pounds per cow containing 24.9 pounds of dry

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matter. Their decline in milk yield was 6.5 per cent for the 42-day period. The superiority of both the hay and silage cut at an immature stage over the full-head hay and silage is evident.

The data indicate that, pound for pound, the dry matter in the Sudan-grass silage was more valuable in maintaining the milk yield than was the dry matter in field-cured hay made from Sudan grass cut at the same stage of maturity.

The results of four years' experiments with Sudan-grass pasture as a grazing crop for dairy cattle are given, and the calculated yields of nutrients from grazing are compared with the yield of nutrients from Sudan-grass hay when cut at the first-heads-out stage. These grazing experiments again emphasize the close correlation of distribution of rainfall during the grazing months with the carrying capacity of the pasture in cow-days per acre and the calculated production of nutrients.

The grazing season averaged 100 days in length, but the total number of cow-days per acre varied from 52.8 in 1930 to 94.8 in 1928 and 1929, with an average of 75 for the four years.

More than 50 per cent of the grazing was obtained in July, and the remainder was fairly equally distributed between August, September, and October.

The calculated total digestible nutrients produced per acre by the pasture followed closely the carrying capacity in cow-days per acre. The average quantity produced per acre for the four years was 1,139.6 pounds. On this basis of calculation 0.67 acre of Sudan-grass hay cut in the first-heads-out stage produced the equivalent in edible nutrients of 1 acre of grazed Sudan-grass pasture. This is the equivalent of 33 per cent more nutrients secured per acre in the form of Sudan-grass hay cut at the first-heads-out stage than were secured from Sudan grass when grazed.

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AGRICULTURAL INVESTIGATIONS AT THE HUNTLEY (MONT.) FIELD STATION, 1927-1930

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United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 353 MAY 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

AGRICULTURAL INVESTIGATIONS AT THE HUNTLEY (MONT.) FIELD STATION, 1927–1930

By DAN HANSEN, *Associate Agronomist and Superintendent, Division of Western Irrigation Agriculture, Bureau of Plant Industry;* A. E. SEAMANS, *Associate Agronomist, Division of Dry Land Agriculture, Bureau of Plant Industry;* and D. V. KOPLAND, *Assistant Dairy Husbandman, Bureau of Dairy Industry*

In Cooperation with the Montana Agricultural Experiment Station

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INTRODUCTION

The work of the Huntley field station, which is located on the Huntley reclamation project in the Yellowstone Valley of southern Montana, deals with investigations in the production and utilization of crops on both irrigated and dry land as well as experiments with dairy cattle, hogs, and sheep. The station is maintained cooperatively by the Division of Western Irrigation Agriculture of the Bureau of Plant Industry, United States Department of Agriculture, and the Montana Agricultural Experiment Station, and facilities are provided for cooperative work by various other divisions of the Department of Agriculture as well as the various departments of the Montana station.

This report presents the results of the investigational work during the four years 1927 to 1930, inclusive, as well as a summary of the more important experiments that have been under way over longer periods. Figure 1 illustrates the location of the fields comprising the station tract and the cropping system in effect in 1930.

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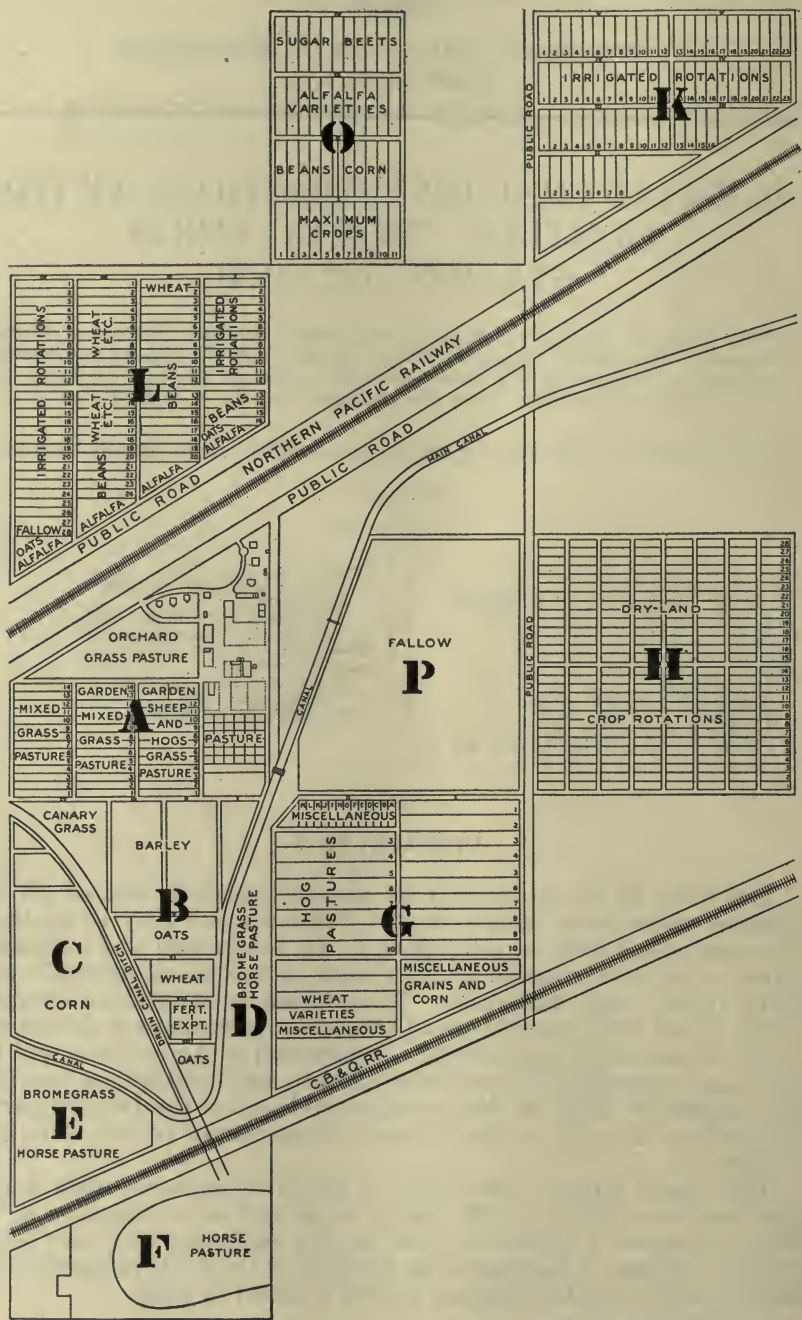

FIGURE 1.—Arrangement of fields and location of experiments at the Huntley field station in 1930

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CLIMATIC CONDITIONS

Weather conditions were particularly favorable during 1927, when the total rainfall was 21.39 inches as compared with an average of 14.27 inches over the 20-year period 1911 to 1930, inclusive, during which climatic measurements have been recorded at this station. The rainfall during each of the three years 1928 to 1930, inclusive, was below normal and amounted to 12.93, 11.80, and 12.28 inches, respectively. Yields of dry-land crops were low during these years, and irrigated crops required much more than the usual amount of water. Precipitation during the spring months was particularly low, and it was necessary to irrigate to provide moisture for seed germination for most crops. The frost-free period during the years 1928 to 1930 was also shorter than the average of 126 days. The frost-free period in 1928 was 112 days, in 1929 it was 103 days, and in 1930 it was only 89 days. In spite of the low rainfall and the short period free from frost in 1930, favorable crop yields under irrigation were obtained, and yields of sugar beets were higher than in any other year in the history of the Huntley project. Weather conditions were favorable for the harvest of sugar beets and other late crops during the entire 4-year period. There was no serious injury from severe storms or hail.

Table 1 gives a summary of the climatological observations during the 20-year period 1911 to 1930, inclusive.

TABLE 1.—*Summary of climatological observations at the Huntley field station during the 20-year period 1911–1930*

PRECIPITATION (INCHES)

Item	January	February	March	April	May	June	July	August	September	October	November	December	Total
Average, 1910–1930	0.79	0.42	0.80	1.28	2.13	2.28	1.31	0.92	1.44	1.16	0.86	0.88	14.27
1927	1.06	.15	.12	3.38	5.09	2.21	.94	2.85	1.14	.31	1.94	2.20	21.39
1928	2.75	.06	.24	1.07	.84	1.45	1.66	1.01	.36	1.77	.58	1.14	12.93
1929	1.21	.97	1.68	.76	.50	2.17	.49	.17	1.41	.84	.58	1.02	11.80
1930	.87	.39	1.34	1.86	.61	1.25	1.05	1.15	1.23	2.19	.34	[1] T	12.28

EVAPORATION (INCHES)

Average, 1911–1930	-----	-----	-----	3.458	4.925	6.105	7.484	6.762	4.297	-----	-----	-----	33.031
1927	-----	-----	-----	3.267	3.963	4.838	6.688	5.447	3.577	-----	-----	-----	27.780
1928	-----	-----	-----	3.654	6.395	5.452	6.883	6.425	4.650	-----	-----	-----	33.459
1929	-----	-----	-----	3.756	4.951	6.379	8.069	7.341	3.921	-----	-----	-----	34.417
1930	-----	-----	-----	4.444	6.193	7.706	8.206	6.615	4.134	-----	-----	-----	37.298

DAILY WIND VELOCITY (MILES PER HOUR)

Highest:													
1911–1930	22.2	14.1	27.8	17.8	17.5	11.0	27.5	7.9	10.5	29.4	25.0	26.6	------
1927	8.2	8.9	8.6	6.4	9.4	6.2	3.6	3.3	6.5	6.3	6.3	8.6	------
1928	11.2	9.5	8.8	7.2	10.7	5.4	5.3	7.7	7.8	9.3	7.9	8.6	------
1929	9.0	10.4	11.3	10.8	9.4	9.4	4.9	5.2	6.8	6.1	10.1	10.5	------
1930	13.2	8.8	8.9	9.0	12.2	11.0	6.5	6.6	6.2	6.6	14.2	10.1	------
Lowest:													
1911–1930	.1	.2	.1	.6	.2	.1	.1	.3	.1	.1	.1	.1	------
1927	.6	.6	.3	.8	1.2	.1	.4	.5	1.0	.3	.5	.1	------
1928	.1	1.1	2.1	.8	.4	1.6	.2	1.0	1.2	.9	.8	.6	------
1929	.7	1.2	1.1	2.0	1.7	.2	.9	1.0	.6	.5	.9	.1	------
1930	.5	.4	.3	1.9	.9	1.8	1.1	.3	.6	.2	.9	1.6	------
Mean:													
1911–1930	4.9	4.4	4.5	5.0	4.6	3.5	3.0	3.0	3.3	3.5	3.9	4.6	------
1927	3.8	3.5	4.2	3.8	3.8	1.8	1.7	1.7	2.1	2.2	2.9	3.2	------
1928	4.0	4.4	4.6	4.5	3.6	3.4	3.0	2.8	3.1	3.4	3.5	4.6	------
1929	4.3	4.6	4.6	4.5	4.0	3.3	2.5	2.9	2.8	2.8	4.6	3.9	------
1930	4.4	4.1	4.0	4.9	4.9	4.3	3.1	2.8	2.7	2.3	4.0	4.7	------

[1] T=trace.

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TABLE 1.—*Summary of climatological observations at the Huntley field station during the 20-year period 1911–1930*—Continued

TEMPERATURE (° F.)

Item	January	February	March	April	May	June	July	August	September	October	November	December	Total
Absolute maximum:													
1911–1930	65	70	80	88	99	107	105	103	96	91	75	67	------
1927	57	51	72	84	85	96	100	90	96	84	62	51	------
1928	52	52	80	85	93	87	97	99	93	84	68	61	------
1929	44	40	72	77	89	97	100	99	96	80	60	52	------
1930	52	70	64	85	88	97	105	98	90	72	72	60	------
Absolute minimum:													
1911–1930	−40	−38	−37	4	17	31	38	29	16	−15	−28	−42	------
1927	−30	−10	7	19	26	37	40	40	26	18	−2	−42	------
1928	−33	−8	17	11	27	34	45	37	25	13	9	−17	------
1929	−40	−37	10	17	17	34	38	45	25	16	−11	−26	------
1930	−35	2	−8	19	30	31	46	29	29	14	−12	6	------
Mean:													
1911–1930	18	24	33	45	54	64	71	69	57	45	33	22	------
1927	19	25	36	43	50	62	68	66	56	49	28	9	------
1928	21	26	40	43	61	60	70	66	57	44	35	25	------
1929	6	11	37	43	52	62	72	73	54	49	31	21	------
1930	6	35	32	53	55	64	74	72	59	41	34	33	------

KILLING FROSTS

Year	Last in spring		First in autumn		Frost-free period
	Date	Minimum temperature	Date	Minimum temperature	
		° F.		° F.	Days
1911	May 26	32	Sept. 18	28	115
1912	May 12	28	Sept. 15	31	126
1913	May 5	31	Sept. 19	29	137
1914	May 12	32	Oct. 6	31	147
1915	May 21	32	Sept. 19	32	121
1916	May 16	30	Sept. 13	31	120
1917	May 31	31	Sept. 28	32	120
1918	May 21	32	Oct. 7	28	139
1919	May 7	29	Sept. 27	32	143
1920	June 3	32	Sept. 24	32	113
1921	May 14	32	Sept. 9	32	118
1922	May 5	31	Sept. 28	29	146
1923	May 15	28	Oct. 11	30	149
1924	May 26	27	Sept. 14	32	111
1925	May 15	29	Sept. 30	32	138
1926	Apr. 26	31	Sept. 18	28	145
1927	May 18	32	Sept. 19	28	124
1928	May 31	31	Sept. 20	31	112
1929	May 27	30	Sept. 7	25	103
1930	June 3	31	Aug. 31	29	89
Average	May 18	----------	Sept. 21	----------	126

AGRICULTURAL CONDITIONS ON THE HUNTLEY RECLAMATION PROJECT

CROPS

The total cropped area of the Huntley reclamation project has increased during the period covered by this report and in 1930 amounted to 23,487 acres, according to the annual crop census furnished by the Bureau of Reclamation of the United States Department of the Interior. During the 10 years previous to 1927 the cropped area remained fairly constant and averaged slightly less than 20,000 acres.

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The total irrigable area of farms reported in 1930 amounted to 26,639 acres, the difference between this figure and that for the cropped area representing land occupied by farmsteads, roads, and ditches. The total amount of land that can be irrigated by the Huntley Canal is 32,500 acres. That part of the project not represented in the irrigable area includes heavy, salty lands that are slow of reclamation and are classed as temporarily unproductive. The increase in the cropped area in recent years indicates that some of these marginal lands are slowly coming into production.

In order to show the general trend of crop acreages during the history of the project, Table 2 has been prepared. This table gives the acreage of each of the principal crops each year during the 18-year period 1913 to 1930, inclusive.

TABLE 2.—*Acreage of principal crops and total acreage of all crops grown on the Huntley reclamation project, 1913–1930*

[From reports of the Bureau of Reclamation]

Year	All crops	Alfalfa	Sugar beets	Beans	Barley	Corn	Oats	Summer pasture	Potatoes	Wheat
1913	15,798	4,848	4,475	--------	191	326	3,942	--------	99	1,177
1914	17,068	6,038	4,274	--------	363	497	3,226	--------	120	1,663
1915	18,203	5,287	5,402	--------	415	509	2,514	1,478	80	2,869
1916	18,581	5,422	5,264	--------	298	174	2,628	1,393	54	2,624
1917	19,104	6,002	3,366	--------	109	186	2,420	1,451	164	4,330
1918	19,265	6,776	1,963	--------	75	203	2,006	1,091	73	6,306
1919	19,310	7,045	1,136	--------	267	179	1,977	1,389	40	6,518
1920	20,021	7,468	2,330	--------	324	392	1,764	2,074	78	5,098
1921	18,782	5,538	3,178	--------	247	375	1,630	1,479	185	5,469
1922	19,523	6,167	3,106	11	223	425	1,434	1,670	149	5,793
1923	18,776	5,463	4,630	120	264	1,319	1,118	2,042	68	3,075
1924	19,768	5,724	5,929	540	222	956	912	2,335	21	2,212
1925	19,309	5,578	4,456	1,279	553	765	1,262	[1] 449 [2] 673	26	3,701
1926	19,789	5,746	4,767	1,075	570	369	997	2,011	39	3,858
1927	20,437	5,274	4,587	1,045	1,397	433	1,014	[1] 1,217 [2] 905	75	3,989
1928	22,737	5,155	2,685	2,777	1,870	235	834	[1] 1,830 [2] 345	29	5,324
1929	23,483	5,411	4,297	4,074	2,332	362	761	[1] 1,842 [2] 1,304	14	2,552
1930	23,487	5,187	4,988	3,667	2,199	216	772	[1] 1,248 [2] 3,263	38	1,455

[1] Cultivated pasture.
[2] Miscellaneous pasture, including native and poor cultivated.

As indicated in Table 2, alfalfa continues to occupy the largest acreage of any single crop and is grown each year on about one-fourth of the total cropped area of the project. While a small quantity of the alfalfa hay is marketed and shipped from the project, the larger part of it is used locally.

The sugar-beet acreage in recent years has remained between 4,000 and 5,000 acres except in 1928, when it dropped to 2,685 acres. The decrease in that year was due to the failure of growers and the sugar manufacturers to reach a satisfactory agreement as to the price to be paid for the crop. The yield of sugar beets has averaged about 10.4 tons per acre during the 18-year period 1913 to 1930, inclusive. In 1930 the yield was 14.13 tons, which was the highest in the history of the project.

Beans have become an important crop on the project in recent years, and in 1929 more than 4,000 acres were in this crop. The principal

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variety grown is Great Northern, although garden seed beans are produced to a limited extent. The garden beans are grown under contract with eastern seed firms.

The acreage cropped to barley has also increased in recent years. The maximum amount of 2,332 acres was grown in 1929, and there was only slightly less than this in 1930. This crop yields well under conditions on the project and makes excellent feed for stock.

The production of wheat declined from 5,324 acres in 1928 to 1,455 acres in 1930. Low prices were responsible for this decline, and wheat has been replaced to a large extent as a cash crop by beans, for which prices have been more favorable.

Irrigated pastures are also an important crop on the project and occupy substantial acreages. While some of the land used for this purpose is included in the poorer, heavy soils, there are also more than 1,000 acres of the more productive land used for this purpose. These cultivated pastures for the most part are seeded to a mixture of grasses recommended in an earlier publication.[1] This mixture is found to have a high carrying capacity and to give returns that compare favorably with returns from other crops.

LIVESTOCK

Surveys made by the Bureau of Reclamation each year since 1914 indicate that there have been no significant changes in the numbers of the various classes of livestock on the Huntley project in recent years. It appears from observation of the conditions on the project that the livestock industries have not developed to the extent to which they could be developed with profit and that for a better balanced and more permanent type of farming more stock should be maintained on project farms. This apparent lack of interest in keeping more livestock is probably accounted for by the fact that a large number of these farms are operated by tenants who are interested mainly in growing cash crops.

The numbers of the various classes of livestock on project farms for the 17-year period 1914 to 1930, inclusive, are given in Table 3.

TABLE 3.—*Number of livestock on farms on the Huntley reclamation project, 1914–1930*

Year	Horses	Mules	Beef cattle	Dairy cattle	Sheep	Hogs	Fowls	Bees (hives)
1914	2,008	53	2,921		847	4,612	23,345	249
1915	1,961	53	3,316		6,198	4,866	18,758	288
1916	1,961	58	1,982	1,753	3,729	2,791	16,418	282
1917	2,145	80	1,795	1,949	1,974	2,363	16,920	296
1918	2,120	51	1,813	1,920	1,130	2,391	15,856	424
1919	2,297	46	2,631	2,040	2,115	3,097	21,456	458
1920	2,041	34	1,312	1,804	2,352	1,885	18,232	180
1921	1,865	58	1,765	1,542	1,486	1,365	18,500	442
1922	1,875	61	1,395	1,951	1,310	1,622	23,036	210
1923	1,547	33	751	1,534	2,384	1,190	20,214	193
1924	2,158	60	1,801	2,250	3,998	1,600	21,644	187
1925	2,027	45	1,658	1,968	7,439	1,572	24,015	435
1926	2,089	47	986	2,006	10,836	1,674	46,279	454
1927	1,898	42	911	1,640	4,739	1,676	23,141	148
1928	1,902	42	599	1,754	4,439	2,807	23,227	545
1929	1,944	56	772	2,306	4,820	1,929	24,537	584
1930	1,813	45	1,568	1,986	6,889	1,657	25,884	1,180

[1] HANSEN, D. IRRIGATED PASTURES. Mont. Agr. Expt. Sta. Bul. 166, 12 p., illus. 1924.

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The largest number of sheep was reported in 1926. Probably two-thirds of these were lambs brought in from the range for winter feeding and fattening for market, although from 2,000 to 3,000 sheep are maintained on project farms the year around, principally in small farm flocks of usually not more than 100 head.

Beef cattle are for the most part brought to the project for fattening for market and are usually fed over a period of four to five months during the winter season. Sugar-beet by-products, including tops and pulp, are utilized as part of the ration for feeding both cattle and lambs.

The number of hogs on the project has usually not exceeded 2,000. In recent years the small number of hogs raised has hardly been sufficient to supply local demands.

The poultry industry has never been developed extensively, and the fowls are kept in small farm flocks of 100 birds or less.

In 1930 there were nearly 1,200 hives of bees, or more than double the number in any previous year reported, and there are a few fairly large apiaries. Sweetclover and alfalfa furnish the principal pasture for bees, and honey of excellent quality is produced.

IRRIGATED-CROP EXPERIMENTS

CROP ROTATIONS [2]

The principal investigational work with irrigated crops at the Huntley field station consists of an extensive series of crop-rotation experiments. These experiments include a total of 43 rotations and continuous cropping and involve the use of one hundred nine ¼-acre plots. Crops grown in these experiments are those of principal importance locally and include alfalfa, sugar beets, potatoes, oats, wheat, beans, corn, flax, and sweetclover. These crops are grown in rotations of various lengths of from one to six years and in various sequences and with various treatments.

The purposes of this experiment are to obtain information as to suitable rotations for this section and to determine the value of alfalfa, other legumes, and manure when used in the rotation. In order to measure the value of legumes and manure, similar rotations that do not include these crops and treatments are used for comparison. Each of the crops used in the experiment is also grown continuously on the same plot each year.

The first of the rotation work was begun in field K in 1912. In this field there are three 6-year, three 4-year, three 3-year, and eleven 2-year rotations in addition to 9 continuously cropped plots. In 1916 additional rotations were begun in field L–IV to supplement those in field K. These rotations involved the same crops as certain of the earlier rotations, but the crops were arranged in different sequences.

In 1927 two 4-year rotations, one 3-year rotation, and one continuously cropped plot were added to field L–I. These rotations included the use of beans and sweetclover, crops that are not included in any of the earlier rotations. In two of the rotations in field L–I sweetclover and corn are pastured by sheep. A list of all of the rotations in these experiments follows.

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[2] See also the following publication: HASTINGS, S. H., and HANSEN, D. IRRIGATED CROP ROTATIONS IN SOUTHERN MONTANA. U. S. Dept. Agr. Tech. Bul. 144, 32 p., illus. 1929.

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Field K

(Rotations begun in 1912)

Continuous Cropping

1. Oats.
2. Sugar beets.
3. Wheat.
4. Potatoes.
6. Corn.
8. Alfalfa.
9. Flax.
10. Sugar beets (manure).[3]
11. Corn (manure).[3]

Two-Year Rotations

16. Oats, corn.
18. Wheat, sugar beets.
20. Potatoes, sugar beets.
21. Potatoes (manure), sugar beets.
22. Oats, sugar beets.
23. Oats (manure), sugar beets.
24. Oats, potatoes.
25. Oats (manure), potatoes.
26. Potatoes, corn.
27. Oats (followed by rye plowed under), potatoes.
28. Wheat, oats.

Three-Year Rotations

30. Potatoes, oats, sugar beets.
31. Potatoes, oats (manure), sugar beets.
32. Corn, oats, sugar beets.

Four-Year Rotations

40. Potatoes, sugar beets, alfalfa (two years).
42. Oats, sugar beets, alfalfa (two years).
44. Potatoes, oats, alfalfa (two years).

Six-Year Rotations

60. Potatoes, oats, sugar beets, alfalfa (three years).
61. Potatoes, oats (manure), sugar beets, alfalfa (three years).
67. Corn (harvested by hogs), flax, sugar beets, alfalfa (three years, pastured by hogs the third year).

Field L–IV

(Rotations begun in 1916)

Continuous Cropping [4]

1–a. Oats (manure).
2–a. Sugar beets (manure).
4–a. Potatoes (manure).
6–a. Corn (manure).
8–a. Alfalfa (manure).

Three-Year Rotations

34. Potatoes, sugar beets, oats.
35. Potatoes (manure), sugar beets, oats.

Four-Year Rotation

46. Sugar beets, oats, alfalfa (two years).

Six-Year Rotations

64. Potatoes, sugar beets, oats, alfalfa (three years).
69. Corn (two years, harvested by hogs), oats, alfalfa (three years, pastured by hogs the third year).

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[3] These plots cropped continuously to wheat and straw returned from 1912 to 1926; begun in their present form in 1927.

[4] Continuously cropped plots in field L–IV manured every second year, beginning in 1927; not manured previous to that time.

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FIELD L–I

(Rotations begun in 1927)

Continuous Cropping

12. Beans.

Three-Year Rotation

37. Wheat, beans (manure), beets.

Four-Year Rotations

47. Wheat (sweetclover), sweetclover (pastured by sheep), corn (harvested by sheep), sugar beets.

49. Wheat (sweetclover), sweetclover (pastured by sheep), sugar beets (manure), sugar beets.

The arrangement of the fields and the locations of the experiments in 1930 are shown in Figure 1.

The cultural practices for each crop in these rotations were as nearly as possible uniform each year. The practices were generally in keeping with what are considered to be timely and good farming methods; and while necessarily there were occasions when it was not possible to perform certain operations such as irrigating and cultivating exactly as appeared desirable, the treatment for each crop was in general the same in all of the rotations. While crop varieties in some cases were changed in order to use adapted or improved varieties, the variety was always the same each year in all of the rotations.

With 1930 the original rotations in field K completed the nineteenth year, and as the experiments have progressed the differences in returns from the different rotations have become more apparent. In general, the yields from the better rotations that include manure or alfalfa have been maintained or increased, while yields in most cases from continuous cropping and in short rotations that do not include manure or alfalfa are decreasing each year and have for several years been at such low levels as to be unprofitable.

In the following discussion, results in the rotations are considered under main crop heads.

SUGAR BEETS

Table 4 presents the yields of sugar beets in detail for the four years 1927 to 1930 and by 6-year periods from 1912 to 1929. By giving the results in averages for 6-year periods it is possible to show the trend of yields more accurately than by considering each year's yields separately, and to eliminate to a large extent variations in yield that might be due to seasonal differences.

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TABLE 4.—*Annual acre yields of sugar beets (tons) at the Huntley field station for each year from 1927 to 1930 and average yields by 6-year periods from 1912 to 1929*

Rotation No.	Crop sequence	1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
2	Sugar beets (continuous)	9.22	7.72	8.17	8.31	8.91	9.06	8.22
2-a	Sugar beets (manure, continuous)	[1]11.31	6.87	13.76	9.87	-------	10.28	[2] 7.68
10	do [3]	-------	16.61	18.88	20.49	-------	-------	-------
18	Wheat, sugar beets	8.44	[4] 1.33	6.72	2.56	9.04	7.13	5.85
20	Potatoes, sugar beets	12.10	11.04	9.93	13.40	12.14	12.56	11.49
21	Potatoes (manure), sugar beets	15.64	16.74	18.75	19.66	13.85	15.18	17.16
22	Oats, sugar beets	9.77	4.82	5.04	5.18	11.09	8.28	6.59
23	Oats (manure), sugar beets	15.39	14.23	19.71	19.30	12.58	12.25	16.32
30	Potatoes, oats, sugar beets	7.80	6.04	6.29	10.88	7.25	8.58	7.51
31	Potatoes, oats (manure), sugar beets	15.41	17.15	14.57	22.18	10.87	12.53	15.25
32	Corn, oats, sugar beets	8.89	7.82	7.16	7.84	7.59	11.21	9.07
34	Oats, potatoes, sugar beets	10.71	4.35	5.49	5.92	-------	13.15	7.81
35	Oats, potatoes (manure), sugar beets	15.48	12.90	17.23	17.54	-------	14.69	15.01
37	Wheat, beans (manure), sugar beets	16.84	14.15	16.00	23.38	-------	-------	[5] 17.59
40	Alfalfa (2 years), potatoes, sugar beets	14.56	13.79	8.28	5.92	11.85	12.27	13.58
42	Alfalfa (2 years), oats, sugar beets	14.24	10.55	4.00	4.70	9.69	11.13	10.27
46	Oats, alfalfa (2 years), sugar beets	7.69	33.15	6.03	5.01	-------	11.68	7.14
47	Wheat (sweetclover), sweetclover (sheep pasture), corn (sheep pasture), sugar beets	17.94	12.33	16.96	20.39	-------	-------	[5] 16.88
49	Wheat (sweetclover), sweetclover (sheep pasture), sugar beets (manure), sugar beets (first year)	15.57	13.78	20.76	18.55	-------	-------	[5] 17.17
49	Wheat (sweetclover), sweetclover (sheep pasture), sugar beets (manure), sugar beets (second year)	18.74	15.44	21.03	22.99	-------	-------	[5] 19.55
60	Alfalfa (3 years), potatoes, oats, sugar beets	14.32	11.51	7.97	15.07	9.86	13.55	13.49
61	Alfalfa (3 years), potatoes, oats (manure), sugar beets	19.25	19.40	17.15	16.56	14.80	16.26	17.34
64	Oats, alfalfa (3 years,) potatoes, sugar beets	13.75	11.19	10.42	8.00	-------	13.58	12.61
67	Alfalfa (3 years, third year pastured with hogs), corn (harvested with hogs), flax, sugar beets	18.23	17.84	17.62	16.24	13.49	16.01	17.26

[1] Manured every second year beginning in 1927; no manure previously.
[2] Average yield 1924–1926, 4.70 tons; 1927–1929, 10.65 tons.
[3] Cropped continuously to wheat 1912–1926; fallow in 1927 to destroy wild oats.
[4] First seeding resulted in stand failure; stand from second seeding poor.
[5] Rotations started in 1927; average given is for the 4-year period 1927–1930.

The results indicate that in the 2-year rotations not manured, yields have declined consistently in each period except in the case of rotation 20, in which potatoes alternate with sugar beets. In this rotation the last period only shows a decrease and this was not nearly so marked as in rotations where grains alternate with beets. The results in this rotation, as well as in others where beets follow potatoes, indicate that this is a good sequence. The greatest decrease in yield occurred in rotation 22, in which sugar beets follow oats. This rotation showed a decrease of 40 per cent. In rotation 18, in which the crops are wheat and beets, there was a decrease of 35 per cent between the first and last periods.

In rotation 21, in which the crops are potatoes and beets, which is directly comparable with rotation 20 except that the beets receive an application of manure each year, there has been a steady rise in yields, and the average yield of beets during the period 1924 to 1929 was 49 per cent greater than that of rotation 20.

In rotation 23, which consists of oats (manure) and sugar beets, there was a substantial increase in yields in the third over the first 6-year period, although the yields were practically the same in the second as in the first period. During the last six years this rotation gave an average yield of 16.32 tons per acre, as compared with 6.59 tons in rotation 22, in which the crops, oats and sugar beets, are the

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same, but which does not receive manure. The increase, ascribed to the effect of the manure, amounted to 147 per cent.

Yields in the continuously cropped beet plot in field K remained at nearly the same level during the 18 years of the experiment. Comparable figures are not available for the continuously cropped beets in field L–IV, since this rotation was changed in 1927 and the plot has since been manured every second year. However, previous to that time the yields were declining rapidly and during the three years 1924 to 1926 averaged only 4.7 tons per acre. This loss in yield was due to the prevalence of black-rot disease (damping off), which has never been serious in the continuous beets in field K. This condition in the beets in field L–IV has apparently been corrected to a large extent by the application of manure, a yield at the rate of 11.31 tons having occurred the first year after manure was applied.

In considering beet yields in the 3-year rotations not manured, it appears that in the case of two of these rotations (Nos. 30 and 32) the yields have been maintained or slightly increased, while in a third case (No. 34) the yield has decreased. The decline in rotation 34 was due largely to black rot, which apparently affects beets to a much greater extent in all of the rotations in field L–IV than in those in field K, owing presumably, to some difference in soil conditions. This condition is apparently overcome when manure is applied, as indicated by yields in rotation 35, in which the crops and crop sequence are the same as in rotation 34 but in which manure is applied directly preceding the beet. The last 6-year average yield of beets in rotation 35 was at the rate of 15.01 tons per acre, as compared with a yield of 7.81 tons in rotation 34. The effect of manure is apparent again in a comparison of rotations 30 and 31, in which the crops are the same and the only difference in treatment is that manure is applied to the land for the beet crop in rotation 31. (Figs. 2 and 3.) Yields in the latter rotation increased consistently in each period and during the last six years averaged double those of rotation 30.

In the 4-year rotations the yields of sugar beets were maintained or slightly increased except in No. 46, in which sugar beets follow alfalfa directly and in which yields showed a marked decline in the six years 1924 to 1929. Here, again, in recent years there has been serious injury to the beet crop due to the presence of black rot. In rotation 40, in which the sequence is two years of alfalfa followed by potatoes and sugar beets, there has been a slight increase in the beet yields through each 6-year period. As compared with beet yields in rotation 20, in which the crops other than alfalfa are the same, the yield of beets in rotation 40 during the last 6-year period was slightly more than 2 tons higher, presumably owing to the effect of the alfalfa. Comparing yields in rotation 42 with those in rotation 22, in which the crops except alfalfa are identical, it is found that during the last six years beets in No. 42 outyielded those in No. 22 by 3.68 tons per acre, while during the earlier years of the experiment the yield of beets in the rotation containing alfalfa was less than that in the 2-year rotation of oats and beets. Although rotations 47 and 49 have been under way only four years, it is apparent from results so far obtained that the use of sweetclover (pastured by sheep), corn (harvested by sheep), and barnyard manure have had a definitely beneficial influence upon the yield of the succeeding beet crops. Four-year average yields of beets in these rotations have been from slightly less than 17 to more than 19.5 tons per acre. Rotation 37, in which

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the crops are wheat, beans (manure), and sugar beets, has also given almost uniformly good returns since the rotation was started, in 1927.

FIGURE 2.—Sugar beets in rotation 30, in which the crops are potatoes, oats, and sugar beets. The beets in this rotation returned an average annual yield of 7.51 tons per acre during the six years 1924–1929, as compared with an average yield of 15.25 tons from rotation 31, in which the beets were manured each year

The beneficial effect upon yields of sugar beets of the use of both alfalfa and manure is indicated in the returns from the 6-year rotations

FIGURE 3.—Sugar beets in rotation 31, in which the crops are potatoes, oats (manure), and sugar beets. The average annual yield for the six years 1924–1929 was 15.25 tons per acre

61 and 67. In rotation 61 the yields have increased consistently from the beginning. In this rotation, in which the crops are three years of alfalfa followed by potatoes, oats, and sugar beets, manure is

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applied preceding the beet crop. Rotation 60, which has the same crops but is not manured, returned a yield of beets of nearly 4 tons less. (Fig. 4.) Comparing the yields from these rotations respectively with those from Nos. 30 and 31, which have the same crops except alfalfa, it is seen that alfalfa and manure markedly benefit the yields of beets.

Rotation 67, in which the third-year alfalfa and corn are pastured by hogs, is not directly comparable with any of the other rotations, but the increasingly high yields of sugar beets in this rotation indicate the value of including alfalfa and of using livestock to graze some of the crops in the rotation.

In comparing yields in rotation 64 with those in rotation 60, between which rotations the only difference is the sequence of the crops, it is observed that there was a slight drop in yields in rotation 64 during the last 6-year period. Beets in rotation 64 outyielded those in rotation 34 by nearly 5 tons to the acre during the last six years. This is apparently due to three years of alfalfa in the longer rotation.

POTATOES

The yields of potatoes in the irrigated rotations are given in Table 5 in detail for the years 1927 to 1930 and by 6-year periods for the years 1912 to 1929.

TABLE 5.—*Annual acre yields of potatoes (bushels) at the Huntley field station for each year from 1927 to 1930 and average yields by 6-year periods from 1912 to 1929*

Rotation No.	Crop sequence	1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
4	Potatoes (continuous)	104.7	112.0	141.3	125.3	173.6	159.4	111.2
4-a	do	[1] 162.7	155.3	222.0	235.3	-------	232.9	[2] 162.9
20	Beets, potatoes	188.0	75.3	155.3	120.0	245.2	222.8	151.9
21	Beets, potatoes (manure)	177.3	236.0	353.3	262.7	271.6	203.6	256.9
24	Oats, potatoes	115.3	106.6	154.0	124.0	248.2	190.7	140.6
25	Oats (manure), potatoes	277.3	233.3	281.3	350.0	327.8	325.5	285.2
26	Corn, potatoes	137.3	128.6	159.3	150.0	233.1	184.0	130.8
27	Oats (rye), potatoes	74.0	120.6	124.7	85.3	75.8	114.9	105.5
30	Oats, beets, potatoes	154.0	122.6	156.6	200.0	196.1	188.5	148.9
31	Oats (manure), beets, potatoes	190.0	186.6	153.3	251.3	179.3	182.9	170.3
34	Beets, oats, potatoes	190.0	133.3	172.7	191.3	-------	266.5	215.0
35	Beets, oats (manure), potatoes	268.7	282.6	348.7	274.7	-------	297.8	326.5
40	Beets, alfalfa (2 years), potatoes	252.7	196.0	262.0	267.3	239.6	273.1	277.1
44	Oats, alfalfa (2 years), potatoes	216.6	192.0	192.7	229.3	180.5	208.2	217.2
60	Oats, beets, alfalfa (3 years), potatoes	287.3	254.6	268.0	295.3	289.0	286.4	281.6
61	Oats (manure), beets, alfalfa (3 years), potatoes	282.0	272.6	339.3	369.3	308.8	310.1	309.6
64	Beets, oats, alfalfa (3 years), potatoes	339.3	268.0	294.7	351.3	-------	291.6	316.1

[1] Manured every second year beginning in 1927; no manure previously.
[2] Average, 1924–1926, 145.8 bushels; 1927–1929, 180 bushels.

The results indicate that based upon 6-year averages yields have shown a consistent decline in the continuously cropped plot and in the 2-year and 3-year simple rotations, while in the rotations that include manure or alfalfa, or both, yields have either been maintained near the original levels or have shown some increase in the later years of the experiment. Apparently, potato yields have been more favorably influenced by the effect of alfalfa in the rotations than by the use of manure. It must be noted, however, that in most of the manured rotations the manure is applied from two to five years preceding the

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crop of potatoes; but even in rotations in which manure is applied immediately preceding the potatoes the yields in only one of the three rotations thus treated have tended to increase during the last 6-year period. This increase in yield occurred in rotation 35, in which the crops are sugar beets, oats (manure), and potatoes. In rotations 21 and 25, in which manure is applied directly preceding the potatoes, the yields were slightly less during the last 6-year period than in the first.

The lowest yield has resulted consistently from rotation 27, in which potatoes follow oats, with rye seeded in the oat stubble and plowed under for green manure the following spring before potatoes are planted. This appears to be a particularly poor practice, probably owing to the fact that in spring plowing in the heavy soils of this

FIGURE 4.—Sugar beets in rotation 61, in which the crops are alfalfa (three years), potatoes, oats (manure), and sugar beets. The average annual yield of beets in this rotation over a 6-year period was 17.34 tons per acre, as compared with 13.49 tons in rotation 60, which is not manured, and 7.51 tons in rotation 30, which contains neither manure nor alfalfa

field it is found difficult to obtain a satisfactory seed bed and the stand of potatoes has frequently been poor.

Continuous cropping to potatoes resulted in a steady decline in yields during each 6-year period. In one continuously cropped plot manure was applied every second year beginning in 1927, although prior to this time the plot was not manured. The crop showed a marked response in increased yields when manure was applied.

The beneficial effect on the yields of potatoes when alfalfa is included in the rotation is indicated in a comparison of alfalfa rotations with rotations that do not include alfalfa but are otherwise identical. The average yield of potatoes in four alfalfa rotations during the last 6-year period was 271.4 bushels per acre, while the average yield from four comparable rotations that did not contain alfalfa was 152.9 bushels, an increase in favor of the alfalfa rotations of nearly 78 per cent.

The effect of manure in the rotation on the yields of potatoes is indicated in a study of five pairs of comparable rotations. In each

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pair the crops are identical, the only difference being that manure is applied in one and not in the other. The manured rotations during the last 6-year period gave an average yield of 269.7 bushels per acre, while the unmanured rotations gave an average yield of only 187.6 bushels per acre. The increase in favor of the manured rotations amounted to 82.1 bushels, or 43.8 per cent.

OATS

Yields of oats in the irrigated rotations each year for the years 1927 to 1930 and by 6-year periods from 1912 to 1929 are given in Table 6. Comparatively low yields have occurred in the 2-year rotations without manure, and the returns in these rotations have usually shown a decline each year during the later years of the experiment. In a rotation of wheat and oats, yields have been practically at the same low level as in the continuously cropped oats. In both of these rotations in recent years wild oats have become a serious factor adversely affecting yields.

TABLE 6.—*Annual acre yields of oats (bushels) at the Huntley field station for each year from 1927 to 1930, and average yields by 6-year periods from 1912 to 1929*

Rotation No.	Crop sequence	1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
1	Oats (continuous)	37.8	35.6	25.0	31.3	[1] 34.1	37.4	33.6
1-a	do	[2] 73.8	44.3	63.8	43.8	-------	60.3	[3] 51.6
16	Corn, oats	76.2	63.8	57.5	72.6	68.8	65.6	61.5
22	Sugar beets, oats	95.0	92.5	70.0	77.5	87.5	83.8	76.6
23	Sugar beets, oats (manure)	104.9	103.5	71.3	101.0	78.7	74.3	87.2
24	Potatoes, oats	81.2	83.8	62.5	70.5	83.4	71.6	71.9
25	Potatoes, oats (manure)	108.7	132.5	106.3	116.1	91.7	79.2	102.6
27	Potatoes, oats (rye, green manure)	61.6	63.5	42.5	40.6	61.3	57.4	56.1
28	Wheat, oats	43.0	56.5	30.0	26.0	[4] 37.3	[4] 45.9	41.2
30	Sugar beets, potatoes, oats	57.5	78.8	62.5	68.6	68.5	60.6	66.0
31	Sugar beets, potatoes, oats (manure)	83.7	107.5	63.8	67.0	74.3	64.9	80.8
32	Sugar beets, corn, oats	64.7	57.5	46.3	60.1	63.5	52.7	52.9
34	Potatoes, sugar beets, oats	83.8	63.8	76.3	65.8	-------	89.2	71.9
35	Potatoes, sugar beets, oats (manure)	95.0	86.3	80.0	91.4	-------	91.3	81.0
42	Sugar beets, alfalfa (2 years), oats	116.2	120.0	102.5	108.6	83.5	88.5	102.2
44	Alfalfa (2 years), potatoes, oats	116.2	130.0	83.8	108.8	75.8	80.4	101.0
46	Alfalfa (2 years), sugar beets, oats	106.2	127.5	92.5	110.6	-------	88.5	105.4
60	Sugar beets, alfalfa (3 years), potatoes, oats	121.2	137.2	103.8	123.9	85.3	90.4	114.9
61	Sugar beets, alfalfa (3 years), potatoes, oats (manure)	115.0	130.0	138.3	136.3	93.5	88.2	118.2
64	Alfalfa (3 years), potatoes, sugar beets, oats	96.2	108.8	92.5	95.6	-------	88.7	99.1
69	Alfalfa (3 years), third year pastured with hogs, corn (2 years, harvested with hogs), oats	106.2	123.8	112.5	113.9	-------	90.0	107.3

[1] No crop in 1916.
[2] Manured every second year beginning in 1927; no manure previously.
[3] Average, 1924–1926, 42.6 bushels; 1927–1929, 60.6 bushels.
[4] No crop in 1916 and 1919; 5-year average.

In the 2-year rotations in which oats follow a cultivated crop, yields have been slightly higher following sugar beets than following potatoes or corn. This has also held true in 3-year rotations in which these crops precede oats.

The use of manure in the rotation has in all cases had a stimulating effect on yields of oats, although manure is not applied directly to this crop but is used in the rotation from one to five years preceding the oats, depending upon the length of the rotation. In five rotations in which no manure was used the average yield of oats during the 6-

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year period 1924 to 1929 was 80.4 bushels per acre. In five comparable rotations in which the crops were identical with those in the first five rotations but in which manure was applied at some period in the rotation, the average yield of oats was 94 bushels per acre. This was a difference of 13.6 bushels, or an increase of 17 per cent in favor of the manured rotations.

The use of alfalfa in the rotation has resulted in still greater increases in yields of oats than has the use of manure. In most cases, however, alfalfa is only one crop removed from oats, and in one case oats directly follows this crop. In five pairs of comparable rotations oats yielded during the last 6-year period in rotations without alfalfa at an average rate of 73.4 bushels per acre, while in rotations that include alfalfa the average during this time was 107.1 bushels, an increase of 33.7 bushels per acre, or 46 per cent. In general, the yields of oats in rotations that include alfalfa or manure or both have tended to increase during the last 6-year period over yields obtained during the first or second 6 years, while in the 2-year and 3-year rotations not so treated the yields have declined as the experiment has progressed.

CORN

Corn is a crop of minor importance in this section and occurs in only nine of the rotations. In two of these the corn is pastured by hogs and in another by sheep. The results from these pastured plots are considered in this report under "Pasturing irrigated crops by hogs and sheep" (p. 22). Results from the harvested plots are given in Table 7.

Yields of corn have been maintained at near the original levels in the 2-year and 3-year rotations, as indicated by average yields during the three 6-year periods. Corn in a 2-year rotation with potatoes has outyielded corn in a rotation with oats by about 10 bushels per acre, and this difference has been fairly constant throughout the 18 years of the experiment. Corn following beets in a 3-year rotation of oats, sugar beets, and corn has given a lower return during each 6-year period than has corn in the rotation with potatoes. The lowest yield was obtained in the continuously cropped plots, and these have shown a marked decrease during the last period. In rotation 6–a there was a marked response in yield when manure was applied in 1927 and 1929. The average yield for the 3-year period 1924 to 1926 was at the rate of only 30.5 bushels, while the average yield for the three years 1927 to 1929, in which manure was applied in two of the three years, was increased to 43.8 bushels.

WHEAT

Wheat is grown in but three of the rotations that were started in 1912 and is included in three of the rotations begun in 1927 in field L–I. Yields of wheat each year from 1927 to 1930 and by 6-year periods from 1912 to 1929 are given in Table 8.

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TABLE 7.—*Annual acre yields of corn (bushels) at the Huntley field station for each year from 1927 to 1930 and average yields by 6-year periods*

Rotation No.	Crop sequence	1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
6	Corn (continuously)	24.5	22.7	10.1	24.2	32.8	28.7	19.3
6-a	do	[1] 39.8	44.3	47.3	42.4		45.8	37.1
11 [2]	Corn (manure) continuously		63.6	46.1	59.3			[3] 56.3
16	Oats, corn	27.3	41.3	23.3	41.2	35.1	39.6	32.5
26	Potatoes, corn	37.5	45.6	38.3	46.4	43.9	48.9	43.3
32	Oats, sugar beets, corn	42.6	41.8	25.9	37.3	38.1	45.9	37.5

[1] Manured every second year beginning in 1927; no manure previously.
[2] Rotation started in 1928. This plot cropped continuously to wheat from 1912 to 1926, inclusive. Fallow in 1927 to destroy wild oats.
[3] Average 1928 to 1930, inclusive.

Yields in the continuously cropped plot and in the 2-year rotation No. 28, in which wheat alternates with oats, have been extremely low almost from the beginning of the experiment. Soon after these cropping systems were begun these plots became infested with wild oats, which has been one of the chief factors in limiting yields. Yields in rotation 18, in which wheat alternates with sugar beets, have been maintained at near the same level during most of the years of the experiment.

In rotations 37, 47, and 49, which were started in 1927 and in which wheat in each case follows sugar beets, wheat occupies a more favorable place in the rotation, and increasingly high yields have been obtained during the four years.

TABLE 8.—*Annual acre yields of wheat (bushels) at the Huntley field station for each year from 1927 to 1930 and average yields by 6-year periods from 1912 to 1929*

Rotation No.	Crop sequence	Yield, bushels per acre						
		1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
3	Wheat, continuous	5.8	19.3	9.3	11.1	21.1	18.0	13.6
18	Sugar beets, wheat	45.0	35.4	36.7	34.0	37.3	29.5	37.3
28	Oats, wheat	11.5	22.9	11.3	16.8	17.4	19.4	15.7
37	Beans (manure), sugar beets, wheat	33.5	42.0	36.7	47.5			[1] 39.9
47	Sweetclover (pastured by sheep), corn (harvested by sheep), sugar beets, wheat (sweetclover)	28.7	36.0	31.3	43.4			[1] 34.9
49	Sweetclover (pastured by sheep), sugar beets (manure), sugar beets, wheat (sweetclover)	29.3	46.0	41.3	49.9			[1] 41.6

[1] Rotations started in 1927; average yields are for the 4-year period 1927–1930.

FLAX

Flax appears in but two cases in the rotation experiments. In one case it is grown continuously on the same plot and in another in a 6-year rotation of alfalfa (three years), corn, flax, and sugar beets. In this rotation the third-year alfalfa and the corn are harvested by

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hogs. Exceptionally high yields of flax have been obtained in this 6-year rotation. Returns from continuous cropping were low after the first two or three years, and during the last 6-year period the average yield was only about one-half the yield during the first 6-year period.

Yields in the 6-year rotation would indicate that flax might be grown with the expectation of obtaining satisfactory yields on irrigated lands under certain favorable conditions. There are, however, some difficulties in handling flax as an irrigated crop unless the field is uniformly drained so that maturity of the crop is uniform. The presence of low, poorly drained spots in a field causes continued blooming and uneven ripening of the crop.

Yields of flax for the years 1927 to 1930, as well as average yields by 6-year periods from 1912 to 1929, are given in Table 9.

TABLE 9.—*Annual acre yields of flax (bushels) at the Huntley field station for each year from 1927 to 1930 and average yields by 6-year periods from 1912 to 1929*

Rotation No.	Crop sequence	1927	1928	1929	1930	6-year average		
						1912–1917	1918–1923	1924–1929
9	Flax (continuous)	4.3	6.3	4.3	7.4	10.8	6.4	5.3
67	Sugar beets, alfalfa (3 years, third year pastured by hogs), corn (harvested by hogs), flax	33.2	27.4	22.9	22.6	29.9	21.1	25.8

BEANS

Beans were not included in any of the original rotations, as this crop has not been of local importance until within recent years. A 3-year rotation of sugar beets, wheat, and beans (manure) was started in the new rotations in field L–I in 1927. Also beans are grown continuously on one plot in this field. The variety grown is Great Northern, which is the principal variety in the locality. Satisfactory yields were produced during the four years both in the continuously cropped plot and in the rotation, although there was some evidence of injury from mosaic disease in the plot continuously in beans the last two years. Yields and related data are given in Table 10.

TABLE 10.—*Annual acre yields of beans (bushels) in the irrigated rotation experiments at the Huntley field station, 1927–1930*

Rotation No.	Crop sequence	1927	1928	1929	1930	Average
12	Beans (continuous)	41.1	36.4	31.1	37.1	36.4
37	Sugar beets, wheat, beans (manure)	44.9	34.1	38.9	42.1	40.0

MAXIMUM CROP PRODUCTION

A cropping experiment to test the maximum yielding capacity of irrigated soils at the Huntley station has been under way since 1926. In this experiment it has been the aim to embody such cultural meth-

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ods and crop sequences as have been found conducive to high yields in the older irrigated rotation experiments and in other cropping work of the station.

The experiment involves the use of eleven ¼-acre plots, and seven crops of local importance are grown in a combination of two rotations, although slight changes have been made in the crop sequence at various times. The entire series was in alfalfa for several years prior to beginning the experiment. During 1926 and 1927 seven plots remained in alfalfa, and the other crops included in the series during these two years were corn, potatoes, oats, and sugar beets. In 1928 wheat and beans were added. From 1928 to 1930, inclusive, two of the five alfalfa plots were broken up each year, one being followed by corn and the other by potatoes. Oats followed corn and beans followed oats. Beets were grown after potatoes, and wheat after beets. Before plowing in the fall, manure at the rate of 16 spreader loads per acre was applied to the plots to be planted to cultivated crops. For the grain crops the land was not manured or plowed but was prepared by the use of disk and harrow or duck-foot cultivator and harrow immediately before seeding. In 1930 for the first time treble superphosphate was applied at the rate of 100 pounds per acre to sugar beets, wheat, and oats at the time of seeding. Table 11 presents the yields obtained in this experiment.

TABLE 11.—*Annual acre yields in maximum crop-production experiment at the Huntley field station, 1926–1930*

Crop	1926	1927	1928	1929	1930	Average
Alfalfa, third year ..... tons	----------	5.86	5.88	5.92	6.98	6.16
Corn ..... bushels	72.5	65.7	69.2	60.4	60.0	65.6
Potatoes ..... do	490.6	560.0	492.6	563.7	336.0	488.6
Oats ..... do	92.5	121.2	136.3	128.7	121.6	120.1
Sugar beets ..... tons	22.34	22.00	22.00	19.96	24.51	22.16
Wheat ..... bushels	----------	----------	65.3	58.0	76.6	66.6
Beans ..... do	----------	----------	48.3	48.9	42.7	46.6

Except for seasonal variations, yields have been fairly uniform. The years 1929 and 1930 were not especially favorable for corn, and the yield of 60 bushels in each of these years was less than during the preceding years. In both 1929 and 1930 it was necessary because of drought to irrigate early to provide moisture for seed germination, and this situation reacted unfavorably on stands and on the early growth of some of the crops. A comparison of average yields in this experiment with the averages obtained on the Huntley project over the same period indicates that the irrigated lands of the project have possibilities of producing yields materially in excess of those formerly considered possible.

EXPERIMENTS WITH BEANS

Experiments with field beans have been carried on at the Huntley station in cooperation with the Montana Agricultural Experiment Station since 1925. These experiments have included tests of a large number of selections, comparative-yield tests with dry-land and irrigated seed, and fertilizer tests, all with the Great Northern variety.

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BEAN SELECTIONS

Beginning in 1925, a large number of individual plant selections of Great Northern beans have been made each year. These selections were made with a view to improving type, yield, and disease resistance of this variety. The disease chiefly considered is mosaic. All selections were grown the first year in 40-foot rows, and those that appeared to warrant further trial were grown in succeeding years in larger plots for comparative yield tests and observations on disease resistance.

During the first years of this selection work, disease did not appear to be a serious factor in any of the selections; but in recent years it has become more prevalent, and because of this many of the selections that had previously been considered to be of some value from the standpoint of yield were discarded in 1930. A small number of the earlier selections that appear to be comparatively free from disease and that yield well are being retained for further trial.

In most commercial fields of Great Northern beans two distinct types of pods are found. One of these is of the clear, wax type, and the other is heavier and has bluish stripes. Beans of each of these types were selected in 1924, and these have been grown in comparative yield tests each year since that time with the exception of 1929. Yields obtained in this test are given in Table 12. The results indicate that the clear-pod type has returned uniformly higher yields each year.

TABLE 12.—*Comparative annual acre yields of clear-pod and striped-pod type Great Northern beans (pounds) at the Huntley field station 1925–1930, excluding 1929*

Type	1925	1926	1927	1928	1930	Average
Clear pod	2,264	1,490	2,842	1,707	1,517	1,964
Striped pod	1,947	1,400	2,602	1,543	1,406	1,779

IRRIGATED AND DRY-LAND BEAN SEED

Yield tests of Great Northern beans from seed grown on irrigated land in comparison with dry-land seed have been conducted for four years, beginning in 1926. The seed used in this test was produced originally from the same source. Observations on disease conditions indicated that the beans grown from dry-land seed may have been somewhat less affected by bean mosaic. In three of the four years of the experiment the yields were in favor of the dry-land seed, although the average yields for the four years are slightly in favor of the seed grown under irrigation. The results thus far do not indicate that there is any significant difference. The yields are given in Table 13.

TABLE 13.—*Average annual acre yields of beans (pounds) from seed grown under irrigation and under dry-land conditions, Huntley field station, 1926, 1927, 1928, and 1930*

Source of seed	1926	1927	1928	1930	Average
Irrigated	1,564	2,869	2,113	1,574	2,030
Dry land	1,632	2,525	2,285	1,608	2,012

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FERTILIZER EXPERIMENT

In 1930 a test of phosphate fertilizer for beans was begun. This fertilizer was a treble superphosphate analyzing 42 per cent available phosphoric acid and was applied at the rate of 100 pounds per acre at the time of preparing the seed bed. In this test two plots were fertilized and two check plots were not fertilized. The average yield of the fertilized plots was at the rate of 2,240 pounds per acre, and from the check plots the average yield was 2,224 pounds, a difference not sufficient to be significant.

EXPERIMENTS WITH SUGAR BEETS

FERTILIZER EXPERIMENT

In 1929 and 1930 an experiment with commercial fertilizers for sugar beets was conducted in cooperation with the Division of Soil Fertility of the Bureau of Chemistry and Soils. This experiment is the standard "triangle" experiment carried on by this bureau in several western beet-growing sections and includes the use of nitrogen, phosphoric acid, and potash fertilizers in various proportions as well as each fertilizer element separately. The fertilizer was applied in one operation with the seed at the time of seeding and was used at the rate of 200 pounds total or 40 pounds of plant food per acre.

In 1929 the results indicated that where superphosphate was applied increases in yield varying from 2.5 to 5 tons per acre were obtained, while from the nitrogen and potash fertilizer there was apparently no response in yield of beets. In 1930, when the experiment was conducted in a different field, there were no significant differences in yield that might be attributed to the effect of the fertilizers.

In both years the method of applying the fertilizer directly with the beet seed was satisfactory and produced no bad effects except on plots where nitrogen fertilizer was applied at the heavier rates. In these cases the stands were not satisfactory, and the fertilizer apparently had a depressing effect on the early growth of the beets. On the plots on which superphosphate and potash were applied perfect stands were obtained each year, and in 1929 the early growth of beets on the phosphate plots was more vigorous than that on adjoining unfertilized plots.

METHOD OF THINNING

In 1926 and 1927 an experiment was conducted with sugar beets to determine the effect on yield of leaving the larger plants at thinning time. Commonly not much consideration is given by laborers to the size and vigor of the plants that are left, so long as the stand approximates the desired distance of 12 inches apart in the row. In this experiment special care was taken in one case to leave the larger and more vigorous plants, while in another case for comparative purposes the beets were thinned in the usual way. The experiment was conducted in duplicate, and in all respects other than in the thinning the cultural operations were uniform. Yields are presented in Table 14. In both years the results were in favor of the plots on which the large beets were left at thinning, the average difference amounting to 1 ton per acre in the two seasons.

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TABLE 14.—*Annual acre yields of sugar beets (tons) in method-of-thinning experiment, with the different methods of thinning at the Huntley field station in 1926 and 1927*

Method of thinning	1926	1927	Average
Large plants	17.32	15.61	16.47
Plants not selected	16.01	14.92	15.47

FERTILIZER TESTS WITH POTATOES

Tests of commercial nitrogen fertilizer for potatoes were made from 1927 to 1929, inclusive, and of superphosphate in 1929 and 1930. The nitrogen fertilizer was in the form of ammonium sulphate and was applied at the rate of 400 pounds per acre directly to the potato row at the time of planting. The land used in the nitrogen experiment had never been cropped to alfalfa but was manured for the crop preceding each crop of potatoes. The crop preceding potatoes for 1927 was sugar beets, and for 1928 and 1929 the preceding crops were beans each year. The results are given in Table 15.

TABLE 15.—*Annual acre yields of potatoes (bushels) in nitrogen fertilizer tests at the Huntley field station, 1927–1929*

Ammonium sulphate per acre	1927	1928	1929	Average
400 pounds	430.7	473.3	390.6	431.5
No fertilizer	322.7	386.6	393.3	367.5

Table 15 indicates that in 1927 and 1928 there was a marked increase in yield in favor of the fertilized plots, the average for the two years amounting to nearly 100 bushels per acre, while in 1929 the yields from the fertilized and check plots were approximately the same, the slight difference being in favor of the check plot. The average difference in favor of the fertilized plot for three years was at the rate of 64 bushels per acre.

The phosphorous fertilizer used in the experiment in 1929 and 1930 was treble superphosphate, testing about 43 per cent available phosphoric acid. This fertilizer was applied at the rate of 100 pounds per acre directly at the time of planting. The results of the two years' tests as presented in Table 16 indicate that there was only a slight increase in yield due to the effect of the fertilizer, the average difference in yield between the fertilized and check plots amounting to 13.1 bushels per acre.

TABLE 16.—*Annual acre yields of potatoes (bushels) in phosphate fertilizer test at the Huntley field station, 1929 and 1930*

Fertilizer per acre	1929	1930	Average
100 pounds	410.6	396.6	403.6
No fertilizer	396.0	385.0	390.5

PASTURING IRRIGATED CROPS BY HOGS AND SHEEP

In certain of the irrigated rotations livestock is used to graze alfalfa and sweetclover and to harvest corn. Hogs are used in rotations 67 and 69 to graze the third-year alfalfa and harvest the corn crop, while sheep are used in rotations 47 and 49 to graze sweetclover and in rotation 49 to harvest corn. Rotations 67 and 69 are 6-year rotations, the former including three years of alfalfa followed by corn, flax, and

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sugar beets, and the latter comprising three years of alfalfa followed by corn two years and oats. Rotation 67 was started in 1912 and rotation 69 in 1917. In rotation 47 the crops are wheat, sweetclover (pastured by sheep), corn (harvested by sheep), and sugar beets. The crops in rotation 49 are wheat, sweetclover (pastured by sheep), sugar beets, and sugar beets (manured). These rotations were started in 1927.

ALFALFA, FIELD CORN, AND RAPE FOR HOGS

The pasture season for alfalfa in rotations 67 and 69 is divided into two periods. Fall pigs that have been carried through the winter on a maintenance ration are used during the first period. They are started on the alfalfa at the beginning of the pasture season, which is usually about May 5, and remain until about July 1. For the remainder of the season, which usually extends to September 10, spring pigs are used on the pasture. The pigs while on the alfalfa pasture are fed corn at the rate of 2 pounds of corn for each 100 pounds live weight of the animals. When placed on pasture, the fall pigs weigh from 100 to 125 pounds each and the spring pigs about 50 pounds. Five fall pigs and eight spring pigs are used on the ¼-acre plot, so that the pasture has a carrying capacity of from 2,000 to 3,000 pounds live weight of pigs per acre. The results of pasturing alfalfa by pigs are given in Table 17. The difference in rate of gain between fall and spring pigs is attributed to the difference in size of the pigs when started on pasture.

TABLE 17.—*Results of pasturing third-year alfalfa (¼-acre plots) in irrigated rotations by eight spring and five fall pigs receiving a 2 per cent ration of corn on pasture at the Huntley field station, 1927–1930, and for the 17-year period 1914–1930*

Field and year	Pasturing periods	Total weight of pigs		Gain in weight			Corn ration per 100 pounds of gain	
		Initial	Final	Total	Average daily			
					Fall pigs	Spring pigs	Fall pigs	Spring pigs
	Days	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pound*	*Pounds*	*Pounds*
K, 1927	129	1,000	1,704	704	1.21	0.62	211	259
L, 1927	129	1,000	1,663	663	1.09	.61	233	261
K, 1928	122	1,178	1,884	706	1.38	.60	255	257
L, 1928	122	1,139	1,887	748	1.40	.66	246	234
K, 1929	123	1,124	1,843	719	1.17	.71	315	193
L, 1929	123	1,091	1,791	700	1.16	.69	310	199
K, 1930	126	1,095	1,835	740	1.23	.71	250	234
L, 1930	126	1,092	1,773	681	1.11	.66	273	242
Average, 1914–1930	131	944	1,545	601	1.01	.54	303	248

In rotation 67 the pigs from the alfalfa pasture are used after the pasture season to "hog off" the plot of corn. Five pigs are used on the quarter-acre plot, and an average of 25 days are required to consume all of the corn. In rotation 69 the two ¼-acre plots of corn are also hogged off. In these plots rape is seeded at the time of the last cultivation. This crop usually is about 12 inches high when the corn is matured and furnishes a good supplemental feed for the pigs. The results of hogging corn and rape in these two rotations, calculated to an acre basis, are presented in Table 18.

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TABLE 18.—*Results of "hogging off" corn alone and corn and rape at the Huntley field station, 1927–1930, and average results 1912–1930*

Items of comparison	Rotation 67, corn alone					Rotation 69, corn and rape				
	1927	1928	1929	1930	Average, 1912–1930	1927	1928	1929	1930	Average, 1916–1930
Pigs per acre ..... number	24	24	20	20	22	20	20	20	20	18
Days on test ..... do	26	26	33	35	25	29	26	34	32	33
Total weight per lot per acre:										
Initial ..... pounds	3,200	2,832	2,200	2,872	2,290	2,660	2,326	2,214	2,794	1,745
Final ..... do	3,760	3,748	2,776	3,460	2,984	3,286	3,136	2,720	3,422	2,498
Total gain per acre ..... do	560	916	576	588	694	626	810	506	628	753
Estimated yield of corn per acre ..... bushels	62.0	77.0	73.6	50.0	61.4	67.5	72.0	72.9	55.0	60.9
Estimated grain per 100 pounds gain ..... pounds	620	471	716	476	495	604	497	807	490	452

The results indicate a slight advantage in favor of the corn and rape over corn alone. The estimated amount of grain required per 100 pounds of gain was also in favor of the plots containing rape.

SWEETCLOVER AND FIELD CORN FOR SHEEP

Sweetclover in rotations 47 and 49 is seeded with wheat as a nurse crop and used as pasture for sheep. The pastures are divided into two parts which are grazed alternately in periods of from 10 days to two weeks each. Each part is irrigated when the sheep are removed, in order to promote maximum growth. The one-fourth acre of pasture during each of the three years reported here has had an average carrying capacity at the rate of six to eight ewes and their lambs per acre over an average grazing period of about 100 days. In each year except 1930 the ewes lost weight on pasture; in 1930 on rotation 49 the ewes made slight gains. The average rate of gain made by the lambs per acre was 340 pounds in rotation 47 and 320 pounds in rotation 49. The results in detail are given in Table 19.

TABLE 19.—*Results of pasturing sweetclover by ewes and lambs in rotations 47 and 49 at the Huntley field station, 1928–1930*

Items of comparison	Rotation 47				Rotation 49			
	1928	1929	1930	Average	1928	1929	1930	Average
Days ..... number	129	103	96	109	112	103	96	104
Ewes ..... do	[1] 2	3	2	--------	[1] 2	4	2	--------
Lambs ..... do	[1] 4	6	3	--------	[1] 4	4	3	--------
Total weight of ewes per lot:								
Initial ..... pounds	584	515	347	482	575	799	351	575
Final ..... do	491	441	312	415	476	742	363	527
Gain or loss ..... do	−93	−74	−35	−67	−99	−57	12	−48
Total weight of lambs per lot:								
Initial ..... do	400	394	165	320	455	269	186	303
Final ..... do	492	441	281	405	522	317	311	383
Gain ..... do	92	47	116	85	67	48	125	80
Average weight per ewe:								
Initial ..... do	150.5	171.7	173.5	165.2	156.5	199.8	175.5	177.3
Final ..... do	117.5	147.0	156.4	140.3	115.5	185.5	181.6	160.9
Average gain or loss ..... do	−33.0	−24.7	−17.1	−24.9	−41.0	−14.3	6.1	−16.4
Average weight per lamb:								
Initial ..... do	56.5	65.7	55.0	59.1	63.3	67.3	62.0	64.2
Final ..... do	77.5	73.5	93.7	81.6	80.5	79.3	103.7	87.8
Average gain per lamb ..... do	21.0	7.8	38.7	22.5	17.2	12.0	41.7	23.6

[1] 2 additional ewes and 4 additional lambs were placed on each pasture for a short period in the early part of the season because of extra growth of the pasture.

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Lambs are used to harvest the ¼-acre corn plot in rotation 47. The lambs are placed on the corn plot a short time before the corn is matured and usually eat all the leaves before starting on the ear corn. While on the corn they have access to all the alfalfa hay they will consume. Table 20 presents the results of harvesting corn by sheep in this rotation.

TABLE 20.—*Results of harvesting corn by sheep in rotation 47 at the Huntley field station, 1927–1930*

Items of comparison	1927	1928	1929	1930	Average
Days ..... number	49	46	42	27	41
Lambs ..... do	7	10	10	10	----------
Total weights:					
Initial ..... pounds	700	876	816	1,013	851
Final ..... do	737	1,052	934	1,129	963
Gain ..... do	37	176	118	116	112
Average weights per lamb:					
Initial ..... do	100.0	87.6	81.6	101.3	92.6
Final ..... do	105.3	105.2	93.4	112.9	104.2
Gain ..... do	5.3	17.6	11.8	11.6	11.6
Daily gain ..... do	.11	.38	.28	.43	.30
Feed per 100 pounds gain:					
Corn ..... do	1,500	306	593	603	750
Alfalfa hay ..... do	1,400	682	924	724	932
Total hay consumed ..... do	500	1,200	1,090	840	907
Estimated acre yield of corn ..... bushels	40.0	45.0	50.5	50.0	46.4

DRY FARMING [5]

Experiments with crops on the nonirrigated land of the station have been conducted since 1912 under the supervision of the Division of Dry Land Agriculture, Bureau of Plant Industry, in cooperation with other branches of the Department of Agriculture and with the Montana Agricultural Experiment Station.

The work consists of (1) growing the common field crops in a series of rotations and by several methods of tillage, (2) variety testing of cereals, beans, potatoes, forage crops, and garden crops, and (3) pasturing annual and perennial crops by hogs. In addition, soil-moisture determinations are made on specified plots throughout each season for the purpose of gathering data on moisture penetration, conservation, and depletion, in relation to various cropping and tillage treatments.

The four years covered by this report embrace from the standpoint of dry-land agriculture one of the most productive (1927) and one of the least productive (1930) seasons in the history of the station. In 1927, a year of abundant rainfall and favorable growing conditions, all crops produced relatively high yields irrespective of the tillage method employed. In 1928, precipitation, temperature, and length of frost-free period were below average, and yields were below average for most crops and under most cultural treatments. Satisfactory yields were obtained, however, from crops produced on lands cultivated with a view to moisture conservation and weed control.

The precipitation for 1929 was next to the lowest that has been recorded at the station. Other climatic factors were likewise unfavorable to crop growth. These conditions and the residual effect of the preceding dry year resulted in crop returns generally lower than those in 1928. Approved tillage methods again were reflected in fair yields, although the difference between high-producing and low-producing methods was less in 1929 than in the previous year.

[5] Report prepared by A. E. Seamans.

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The year 1930 was the third consecutive one in which both the annual and the seasonal precipitation were below the average. Light rainfall in the spring together with the scarcity of moisture in the soil at seeding time made starting conditions unusually difficult for most crops. As the season advanced the continued drought in addition to high temperatures resulted in very low yields or complete failures of all crops grown in the dry-land experiments. The growing season of 1930 was the most severe on crops yet experienced at the station.

ROTATION AND TILLAGE EXPERIMENTS

WINTER WHEAT

The Kharkof variety of winter wheat has been used in the rotation experiments since they were begun. This crop yielded well in 1927, the average returns being considerably above the 1913 to 1930 average for all rotations and tillage treatments. As is commonly the case in seasons of favorable rainfall and growing conditions, the differences between the yields of winter wheat from the various tillage methods employed were less than normal, and a relatively satisfactory crop was obtained when even the poorest practices were followed.

The abundance of moisture accumulated in land fallowed during the unusually wet season of 1927 produced in 1928 yields of winter wheat on fallow somewhat above the average. The returns were less than the average.

Winter wheat grown on summer-fallowed land produced in 1929 the highest yields from any of the comparable treatments, but in nearly all of the experiments the returns were less than those harvested in 1928 and were much below the average returns for the period 1913 to 1930.

Because of winter-killing, soil drifting, and spring drought, the stands of winter wheat were poor in 1930, and the plots were reseeded to spring wheat. Drought and hot weather destroyed the wheat in most of the experiments, and on only three plots did the crop grow tall enough to be harvested. The yields obtained from the plots harvested were extremely low.

Table 21 presents the average yields of winter wheat from the various rotations and tillage methods for each of the years under review and for the period 1913 to 1930.

TABLE 21.—*Annual acre yields of winter wheat following different methods of tillage and crop sequences at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield				
			1927	1928	1929	1930 [1]	1913–1930
		Number	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Fall plowed	Winter wheat	4	24.8	5.8	6.4	0	11.3
Subsoiled	do	1	29.7	11.0	9.2	0	12.6
Listed	do	1	21.0	10.8	5.3	0	11.9
Disked grain stubble	do	5	28.4	4.5	4.1	0	10.5
Disked corn stubble	Corn	4	37.5	9.3	12.8	0	18.5
Fallow	Fallow	10	37.7	32.0	15.0	1.3	26.4
Green manured	Winter rye	2	32.0	16.4	8.0	0	18.1
Do	Peas	2	36.3	18.5	10.0	0	22.2
Total or average		29	32.9	17.0	10.3	.5	[2] 19.7

[1] Loss of stand of winter wheat through winter injury and soil drifting necessitated reseeding the plots to spring wheat in 1930, and the yields presented under 1930 are for spring wheat instead of winter wheat.
[2] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

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SPRING WHEAT

Forty-one plots of Kubanka spring wheat were included in the rotation and tillage investigations each year. In these experiments the crop was grown after corn, oats, flax, winter rye, field peas, sweetclover, and spring wheat. The tillage included spring plowing, fall plowing, summer fallowing, listing, subsoiling, disked grain stubble, disked corn stubble, and green manuring.

As was the case with winter wheat, yields of spring wheat during the very favorable year of 1927 were much above the average, and the differences in yield from the various treatments were comparatively small. The highest yield was from a rotation of wheat following flax; summer-fallowed land came next, and the third highest yield was on spring-plowed cornland. Experiments in which spring wheat followed itself were among the least productive.

Yields of wheat in 1928 were all much below those of 1927 and with but few exceptions were below the average for the period of experimentation. Spring wheat grown on fallowed land, on fall-plowed cornland, and following winter rye in a green-manure rotation produced yields above the average.

All rotations returned small yields of spring wheat in 1929. With one exception these yields were less than those harvested in 1928 and were much below the 18-year average of the experiments.

In 1930, the third of a succession of dry years, spring wheat planted on land that had been summer-tilled for three years was the only wheat producing a crop that could be gathered with a binder. The yield obtained on that plot was 21.7 bushels to the acre. Although two other plots of wheat on fallow were harvested, they yielded less than 4 bushels to the acre. On all the other plots the crop dried up before maturity, and no grain was harvested.

The average yields of spring wheat grown in the various rotation and cultural experiments are summarized in Table 22.

TABLE 22.—*Annual acre yields of spring wheat from different methods of tillage and crop sequence at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield				
			1927	1928	1929	1930	1913–1930
		Number	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Fall plowed	Corn	1	23.0	15.2	6.3	0	13.4
Do	Oats	2	23.5	10.4	6.6	0	13.0
Do	Wheat	3	20.1	9.3	5.8	0	10.7
Spring plowed	Corn	1	27.0	7.0	6.8	0	13.6
Do	Oats	1	22.8	6.0	8.5	0	10.9
Do	Wheat	1	24.2	3.8	2.8	0	9.8
Do	Flax	1	29.2	11.7	8.5	0	12.7
Subsoiled	Wheat	1	20.2	10.5	8.7	0	10.5
Listed	do	1	24.5	7.8	6.0	0	12.3
Disked grain stubble	do	4	23.9	6.7	4.4	0	10.1
Disked corn stubble	Corn	12	23.6	9.7	8.6	0	14.5
Fallow	Fallow	10	27.5	20.0	10.1	2.9	19.3
Green manured	Winter rye	1	23.8	18.3	6.0	0	15.9
Do	Peas	1	26.0	14.2	8.0	0	17.9
Do	Sweetclover	1	22.2	13.2	10.5	0	14.2
Total or average		41	24.5	12.2	7.9	.7	[1] 14.8

[1] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

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OATS

The Sixty-Day variety of oats has been used in these experiments since they were begun. The largest yields of this crop have usually been produced on summer-fallowed land, but in 1927—a season of very favorable growing conditions—the yields of oats on fallow were exceeded by the returns from several other cultural treatments. The highest average yield was produced by oats sown on disked cornland. In 1928 oat yields from all tillage methods except fall-plowed barley, fallow, sod, and green-manure treatments dropped below the average production since 1913. Yields were further diminished during the dry season of 1929, and in the third year of drought, 1930, oats were a total failure. The yields of oats in the experiments are shown in Table 23.

TABLE 23.—*Annual acre yields of oats from different methods of tillage and crop sequence at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield				
			1927	1928	1929	1930	1913–1930
		Number	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Fall plowed	Wheat	6	49.8	26.0	17.2	0	28.9
Do	Barley	1	46.9	29.7	23.8	0	29.3
Do	Oats	1	45.9	16.9	14.1	0	23.1
Spring plowed	Corn	2	53.6	16.8	20.3	0	30.0
Do	Wheat	2	47.7	26.5	19.4	0	28.0
Do	Oats	1	46.6	15.0	10.9	0	23.4
Do	Flax	1	48.1	19.4	12.8	0	24.6
Subsoiled	Oats	1	51.6	21.9	10.3	0	22.3
Listed	do	1	55.3	20.9	7.8	0	27.7
Disked corn stubble	Corn	9	57.0	27.7	21.2	0	32.2
Fallow	Fallow	3	52.7	53.3	22.5	0	42.8
Green manured	Winter rye	2	53.3	49.9	13.9	0	35.8
Do	Peas	2	52.2	48.3	15.5	0	38.4
Do	Sweetclover	1	51.9	44.1	12.5	0	32.8
Sod crops	Alfalfa	1	42.8	37.2	14.1	0	25.4
Do	Bromegrass	1	41.9	32.5	12.8	0	25.8
Total or average		35	51.9	31.0	17.7	0	[1] 31.3

[1] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

BARLEY

Hannchen barley was sown on 11 plots in the tillage and rotation experiments during the four years under review. Notwithstanding the favorable season of 1927, barley yields, although higher than the average, were relatively lower than the returns of the other small-grain crops. Barley following winter rye that had been plowed under for green manure was the highest yielding plot. Barley grown on spring-plowed oats stubble ranked second, and that grown on summer fallow third. Barley on the winter-rye green manure again produced the maximum yield in 1928, and that on summer fallow the next largest yield. In 1929 all barley yields with one exception were extremely low, owing to drought and retarded spring growth. Barley on disked flax stubble produced an outstandingly high yield. The crop on this plot came up promptly in the spring and was more fully developed before being checked by drought than was barley on the seed beds prepared otherwise. Drought, high temperatures, and scarcity of available soil moisture combined to make growing conditions in 1930 very unfavorable for barley production. The crop on all plots dried up before reaching maturity, and no yields were obtained. The average yields in the barley experiments are given in Table 24.

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TABLE 24.—*Annual acre yields of barley from different methods of tillage and crop sequence at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield				
			1927	1928	1929	1930	1913–1930
		Number	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Fall plowed	Barley	1	19.2	3.1	1.7	0	9.0
Spring plowed	Oats	1	30.8	8.8	4.6	0	14.8
Do	Barley	1	23.3	2.1	.4	0	11.4
Disked flax stubble	Flax	1	23.8	17.5	24.0	0	17.1
Disked corn stubble	Corn	4	26.1	12.3	3.2	0	17.2
Fallow	Fallow	1	26.7	25.8	2.9	0	18.7
Green manured	Winter rye	1	32.1	31.7	3.3	0	21.1
Do	Peas	1	27.7	20.8	1.5	0	21.2
Total or average		11	26.2	14.4	4.6	0	[1] 17.6

[1] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

FLAX

The Linota variety of flax was used in the rotation and tillage experiments from 1927 to 1930. In 1927 yields above the average were produced on all plots. Flax grown on two plots of spring-plowed corn stubble returned the highest yield. The second highest yield was obtained from flax on fall-plowed cornland. The lowest yields were from the experiment in which flax was continuously cropped on the same land. In 1928 the yields dropped below those obtained in 1927, although the production from some of the tillage methods was still greater than the average. Flax following corn in a rotation or grown on fallow land again yielded well. The drought of 1929 was reflected in very low returns of flax, all methods producing less than average yields. The highest yield of the season was obtained on spring-plowed cornland. This was followed closely by flax on fallow and flax on disked cornland. No yields whatever were obtained in 1930, the crop having dried up before setting seed. In Table 25 are shown the average yields of flax obtained from the various crop sequences and cultural treatments.

TABLE 25.—*Annual acre yields of flax from different methods of tillage and crop sequence at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield				
			1927	1928	1929	1930	1913–1930
		Number	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Fall plowed	Corn	1	18.6	7.9	4.5	0	7.6
Do	Flax	3	8.4	8.1	4.8	0	5.9
Spring plowed	Oats	1	12.9	4.6	3.6	0	6.1
Do	Wheat	1	15.5	8.6	3.6	0	7.5
Do	Corn	2	19.5	10.4	6.1	0	8.1
Do	Flax	2	9.5	2.7	3.3	0	5.9
Subsoiled	do	1	12.3	6.6	2.5	0	5.1
Listed	do	1	11.3	4.3	1.3	0	5.2
Disked corn stubble	Corn	2	15.1	5.0	5.9	0	7.2
Fallow	Fallow	2	11.6	10.7	6.0	0	9.2
Total or average		16	12.9	7.1	4.5	0	[1] 7.0

[1] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

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CORN

Northwestern Dent has been the variety used in the corn experiments since 1912. In 1927 the yields of grain and stover were uniformly high. The maximum yield of grain was obtained from corn continuously cropped on fall-plowed and subsoiled land. Next in order were grain yields of corn following flax on spring plowing and after fall-plowed winter-wheat stubble. Taken as a whole, corn grown on fall-plowed land gave slightly higher yields of grain and stover than was obtained from corn on spring plowing.

The residual effects of the very favorable crop season of 1927 were demonstrated to some extent by the corn crop produced in 1928. Although all corn yields in 1928 were much below those obtained in 1927, there were a number of cultural treatments, notably among the fall-plowed group of plots, that returned yields above the average. The highest yield was from fallowed land.

Most grain yields of corn in 1929 were practically failures, although stover returns were in many cases above those obtained in 1928. In 1930 because of drought and very unfavorable growing conditions the crop failed to mature grain. The stover yields from all treatments were also very much below the average.

The average yields of corn and stover for the various rotation and tillage experiments are given in Table 26.

TABLE 26.—*Annual acre yields of corn from different methods of tillage and crop sequence at the Huntley field station, 1927–1930, and for the 18-year period 1913–1930*

Seed-bed preparation	Preceding crop	Plots averaged	Average acre yield									
			1927		1928		1929		1930		1913–1930	
			Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
		No.	*Bus.*	*Lbs.*	*Bus.*	*Lbs.*	*Bus.*	*Lbs.*	*Bus.*	*Lbs.*	*Bus.*	*Lbs.*
Fall plowed	Oats	4	46.4	3,550	9.3	683	0	1,043	0	280	16.0	1,564
Do	Spring wheat	2	46.0	3,900	14.6	825	.2	1,115	0	320	16.8	1,568
Do	Flax	1	46.9	4,480	22.6	1,700	5.2	1,310	0	370	16.5	2,159
Do	Winter wheat	1	52.5	4,660	23.2	1,300	0	910	0	610	22.9	2,456
Do	Corn	1	46.1	2,140	27.8	1,180	6.5	1,200	0	280	16.7	1,584
Spring plowed	Spring wheat	5	48.8	3,444	11.4	654	1.4	1,322	0	160	17.4	1,634
Do	Oats	13	42.9	3,708	11.7	708	1.2	1,224	0	287	17.4	1,774
Do	Winter wheat	6	42.4	2,283	11.3	497	1.1	960	0	268	16.3	1,533
Do	Barley	3	39.8	2,780	12.2	350	1.3	1,133	0	350	17.2	1,511
Do	Flax	3	52.9	5,030	9.4	807	1.1	1,190	0	260	16.6	1,991
Do	Corn	1	45.6	1,480	16.7	660	4.1	1,560	0	410	16.6	1,404
Subsoiled	do	1	53.2	2,110	29.4	1,420	3.7	1,340	0	300	17.2	1,761
Listed	do	1	45.3	1,700	20.0	1,300	4.5	1,000	0	610	22.4	1,404
Fallow	Fallow	1	44.3	1,980	31.8	1,520	4.8	1,740	0	960	26.5	2,253
Total or average		43	45.2	3,328	13.5	753	1.5	1,179	0	309	[1]17.6	[1]1,706

[1] Because the number of plots was increased after the experiment was begun, the figure given is the average of the average yields obtained each year and not the average of the average yields shown for each method.

VARIETY TESTS

WINTER WHEAT

Ten varieties and selections of winter wheat have been grown in comparison with one another during the four years covered by this report. These trials were conducted on replicated plots as well as in nursery rows each year except 1930, when plots alone were used. Favorable growing conditions in 1927 resulted in yields of all varieties

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well above the average. In 1928 good stands and yields were obtained from the winter wheat grown on plots, but in the rod-row tests poor stands were responsible for yields below the average. The stands of all varieties were uniformly thin in plot and row plantings in 1929, but most of the wheats grown on the plots yielded above the average for the varieties, whereas the production from the rows was less than average. In 1930, because of poor stands and a dry season, the winter-wheat varieties, all of which were grown on plots, made comparatively poor returns. Not only were the yields low, but the quality of the wheat was much below the average. The winter-wheat variety test is summarized in Table 27.

TABLE 27.—*Annual and average acre yields of winter wheat (bushels) grown on dry land in replicated nursery rows and plots in variety tests, at the Huntley field station, 1927–1930*

Variety	1927		1928		1929		1930	Average	
	Plots	Rows	Plots	Rows	Plots	Rows	Plots	1928–1930 plots	1927–1929 rows
Kharkof	40.7	44.4	34.9	27.3	31.7	22.7	8.6	25.1	31.5
Turkey	(1)	43.5	31.5	15.6	33.3	25.5	10.8	25.2	28.2
Montana 36	(1)	38.8	35.5	18.4	28.0	26.5	10.0	24.5	27.9
Kanred	39.3	41.6	35.4	13.8	28.5	22.7	9.7	24.5	26.0
Newturk	(1)	34.0	34.5	15.9	30.5	26.5	10.9	25.3	25.5
Karmont	38.7	38.8	23.9	13.1	25.2	22.7	8.3	19.1	24.9
Alton	38.3	40.6	35.5	12.3	26.2	20.8	7.8	23.2	24.6
Ridit	(1)	34.1	27.0	19.8	27.2	13.2	9.4	21.2	22.4
Hybrid 128	(1)	31.2	33.3	14.3	22.9	21.8	(1)	[2] 28.1	22.4
Burbank Super	(1)	35.0	30.3	13.5	23.5	18.0	(1)	[2] 26.9	22.2

[1] Variety not planted. [2] Average 1928 and 1929.

SPRING WHEAT

There has been no consistency in the number or varieties of spring wheat grown for comparison during the four years. Since 1929 this line of work has been conducted in cooperation with the Division of Cereal Crops and Diseases of the Bureau of Plant Industry. That division supplied seed of 11 of the varieties used in 1929 and 1930. The yields of the spring-wheat varieties grown in 1927 were uniformly good, owing to the favorable season, but the returns of most varieties in the three years following were less each season than those of the previous year. The annual and average yields are given in Table 28.

TABLE 28.—*Annual and average acre yields of spring wheat (bushels) grown on dry land in variety tests at the Huntley field station, 1927–1930*

Variety	1927	1928	1929	1930	Average	
					1927–1930	1929–1930
Hard Federation	30.0	13.7	10.3	(1)		
Reward	(1)	(1)	10.8	4.5		7.7
Kota	24.8	13.9	7.5	(1)		
Peliss	27.3	14.4	6.5	(1)		
Marquis	29.5	13.2	6.8	5.1	13.7	6.0
Acme	25.2	19.7	6.7	4.3	14.0	5.5
Kubanka	28.7	11.4	3.5	7.3	12.7	5.4
Ceres	(1)	(1)	7.2	3.6		5.4
Supreme	24.6	8.0	7.0	3.5	10.8	5.3
Hope	(1)	(1)	6.0	4.3		5.2
Nodak	(1)	(1)	4.0	5.8		4.9
Federation	(1)	(1)	7.3	2.3		4.8
Mindum	(1)	(1)	7.0	2.5		4.8
Reliance	(1)	(1)	5.0	4.5		4.8
Marquillo	(1)	(1)	5.8	2.5		4.2
Champlain (Pringle Champlain)	16.9	19.5	4.0	4.0	11.1	4.0

[1] Variety not planted.

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OATS

Several varieties of oats have been tried from time to time on the dry-land plots, but during the period 1927 to 1930 only four varieties were grown consistently for three or more years. The range in oat yields during these four years has corresponded closely with that of other small-grain crops. The unusually heavy production of all varieties in 1927 was followed by diminished yields in the succeeding seasons until 1930, when the oat crop was a complete failure owing to the extremely unfavorable growing conditions. Table 29 gives the yields of four varieties grown during the 4-year period.

TABLE 29.—*Annual and average acre yields of oats (bushels) grown on dry land in variety tests at the Huntley field station, 1927–1930*

Variety	1927	1928	1929	1930	Average
Markton	105.0	49.3	34.6	0	47.2
Victory	97.8	51.1	30.5	0	44.9
Sixty-Day	76.6	41.6	32.0	0	37.6
Gopher	(1)	55.8	33.6	0	29.8

[1] Variety not grown.

BARLEY

Data on the growth and yield of six varieties of barley have been obtained each year of the period under review. All varieties yielded extremely well in 1927, but in the succeeding years the returns were less than the average. In fact, the drought in 1930 was so severe that all of the barley plantings dried up before maturity, and no yields were obtained. Table 30 presents the average annual yields of barley in these tests.

TABLE 30.—*Annual and average acre yields of barley (bushels) grown on dry land in variety tests at the Huntley field station, 1927–1930*

Variety	1927	1928	1929	1930	Average
Trebi	55.8	10.2	19.4	0	21.4
White Smyrna	50.4	6.6	16.9	0	18.5
Horn	47.9	7.6	15.5	0	17.8
Himalaya	51.0	5.8	10.6	0	16.9
Hannchen	45.2	5.9	2.9	0	13.5
Success	33.8	9.1	7.9	0	12.7

CORN

The object of the variety tests of corn has been to find a variety that will thrive under dry-land conditions and mature a relatively high yield of grain and stover in an average frost-free period of 127 days and that will be adaptable to harvesting by machinery or by livestock. With this in view, a large number of corn varieties and strains have been tried at the Huntley station since 1915. A number of the first varieties to be grown have been discarded as undesirable or have been supplanted by superior strains. Beginning in 1922 a group of varieties was selected for continued trial, this group to be further reduced or enlarged as warranted by the results obtained.

Table 31 presents the yields of grain from 10 varieties of corn, all but 1 of which have been planted each year since 1922. Five of these varieties have matured grain every year except 1925, 1926, 1929, and 1930, during which years the crop was killed by drought. Of these

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five varieties, Northwestern Dent, Falconer, and Minnesota 23 may be harvested by machinery or by livestock, whereas Dakota White Flint and Gehu Flint are suitable for harvesting by livestock only. Payne White Dent was slightly immature in two of the five years that corn was produced, and the late varieties, including Calico, Golden Glow, Minnesota 13, and Rainbow Flint, have frequently failed to mature grain before frost. The late varieties, however, usually have developed grain to the stage where the crop may be used for silage or pasturage, and as the fodder yields of the late types are generally heavy, they may profitably be grown for the purposes suggested.

TABLE 31.—*Annual and average acre yields of corn (bushels) grown on dry land in variety tests at the Huntley field station, 1922–1930*

Variety	1922	1923	1924	1925	1926	1927	1928	1929	1930	Average
Falconer	26.5	27.1	25.8	0	0	52.4	19.2	0	0	16.8
Northwestern Dent	24.8	18.3	37.0	0	0	45.2	14.8	0	0	15.6
Dakota White Flint	22.3	20.1	26.7	0	0	42.9	17.0	0	0	14.3
Minnesota 23	28.7	17.7	29.7	0	0	37.2	14.3	0	0	14.2
Gehu Flint	-------	-------	31.6	0	0	39.5	20.4	0	0	13.1
Payne White Dent	24.5	[1] 28.9	33.5	0	0	[1] 44.8	14.3	0	0	16.2
Golden Glow	21.9	[1] 35.8	[1] 35.9	0	0	[1] 43.6	[1] 6.9	0	0	16.0
Minnesota 13	18.1	[1] 29.9	[2] 29.4	0	0	41.0	[1] 6.9	0	0	13.9
Calico Dent	[1] 17.2	[2] 45.8	[2] 39.0	0	0	[2] 41.8	[1] 4.3	0	0	16.5
Rainbow Flint	[1] 14.8	[2] 63.9	[2] 50.5	0	0	[2] 40.1	[1] 5.8	0	0	19.5

[1] Slightly immature. [2] Very immature.

POTATOES

Variety testing with potatoes has been conducted on dry land at the Huntley station since 1915. During that period a total of 23 varieties and strains have been tried for varying periods of time. Of the varieties used, Bliss Triumph has been planted every year and Rural New Yorker in 15 of the 16 years of testing. Three other varieties—Irish Cobbler, Early Ohio, and Russet Burbank—have been grown for 14 years each, although the years in which they were planted were not consecutive. No marketable potatoes were harvested from any of the varieties in 1919, 1929, or 1930, as the growth of the crop was checked by drought before the tubers attained a commercial size. The yields of eight varieties of potatoes grown in this test for nine or more years are given in Table 32.

TABLE 32.—*Average annual acre yields of potatoes (bushels) grown on dry land in variety tests at the Huntley field station, 1927–1930, and average yields for the periods 1915–1930 and 1927–1930*

Variety	Acre yield (bushels)				Average			
					1915–1930		1927–1930	
	1927	1928	1929	1930	Years grown	Yield per acre	Years grown	Yield per acre
					Number	*Bushels*	*Number*	*Bushels*
Green Mountain	(1)	(1)	(1)	(1)	11	96.1	0	(1)
Early Eureka	165.6	66.0	(2)	(2)	12	82.3	4	57.9
Irish Cobbler	(1)	70.5	(2)	(2)	14	77.9	3	-------
White Ohio	194.3	70.8	(2)	(2)	9	76.7	4	66.3
Rural New Yorker	192.5	30.9	(2)	(2)	15	75.0	4	55.9
Early Ohio	172.7	74.1	(2)	(2)	14	71.5	4	61.7
Bliss Triumph	183.8	62.7	(2)	(2)	16	61.6	4	61.6
Russet Burbank	133.9	25.5	(2)	(2)	14	60.0	4	39.9

[1] Variety not planted. [2] As a result of drought no marketable potatoes were produced.

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ROW-SPACING TEST WITH FIELD BEANS

An experiment to determine the yields of field beans planted in rows 24, 30, and 36 inches apart was begun in 1918. The Early Navy variety was tried in this test from 1918 to 1923, inclusive, and from 1924 to 1930 the Great Northern variety, the bean commonly grown in this locality, was used. Prior to 1924 the beans planted in rows 30 inches apart consistently returned higher yields than did the 24-inch and 36-inch spacings. Great Northern beans planted in rows 36 inches apart have outyielded beans grown in rows 24 and 30 inches apart in three years out of four in which crops have been produced since 1924. The average yields for the 30-inch spacings are, however, a little larger than those obtained from the 24-inch and 36-inch plantings over the 1918–1930 period and also the 1927–1930 period, as shown in Table 33.

TABLE 33.—*Annual average acre yield of field beans (pounds) planted on dry land in row-spacing tests at the Huntley field station, 1927–1930, and averages for the periods 1918–1930 and 1927–1930*

Distance between rows	1927	1928	1929	1930	Average	
					1918–1930	1927–1930
24 inches	1,540	182	0	0	405	431
30 inches	1,550	238	0	0	435	447
36 inches	1,560	220	0	0	408	445

PASTURING DRY-LAND CROPS BY HOGS

The experiments in pasturing dry-land crops by hogs were begun in 1915, for the purpose of determining (1) the suitability of various grain and forage crops for hog pasture, (2) the possibility of arranging a series of crops for the production of palatable forage throughout the season, (3) the agronomic effect on succeeding crops of manure resulting from pasturing, and (4) the economic merits of pasturing hogs on the crops as compared with harvesting them with machinery in the ordinary manner. Both annual and perennial crops were used.

ANNUAL-CROP PASTURES

Prior to 1924 the annual crops used were winter rye, field peas, beardless barley, and corn. These crops were grown in a rotation and were pastured in the order named. The first three crops were grazed by fall pigs, and the corn was harvested by spring pigs. Crops on a duplicate rotation adjacent to the pasture experiment were harvested by machinery and the yields determined. Not only did the duplicate unpastured rotation provide information on the seasonal growth of the varieties of crops pastured, but by comparing the returns from the pastured and the harvested rotations it is possible to determine which method of handling the crops would prove most profitable over a series of years.

Beginning with 1924, spring pigs were used to pasture the annual crops. Mature barley having proved to be unsuitable for "hogging off" under the conditions of the experiment, the pasturing of that crop was discontinued in 1924, and the plot of barley in the pasture rotation has since been harvested by machinery and threshed each year.

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By comparing the yields of barley from the pastured and unpastured rotations the cumulative agronomic effects of pasturing may be measured. In place of the barley pasture, the spring pigs were provided with combination crop pastures consisting of Sudan grass and soybeans, and sorgo and soybeans, which were used to fill the grazing interval between field peas and corn. On all pastures except corn the spring pigs were provided with a supplementary ration of self-fed corn, and skim milk was also fed when available. Throughout the pasture season a similar lot of spring pigs was fed a full ration of shelled corn and skim milk in a dry pen without pasture. The dry-pen pigs were used as a check lot by which the growth of the pigs on pasture was measured and the economy of gains determined. The results obtained in the pasturing experiments vary widely from year to year, owing primarily to the type of season,which may affect the quantity, palatability, and period of production of the forage and consequently the growth made by the hogs.

In 1927, a year of comparatively heavy seasonal rainfall, all crops used for pasturage produced an abundance of forage. Two mature sows and 15 spring pigs were placed on the acre plot of winter rye in the pasture rotation on May 18, when the crop was about 15 inches tall. At that stage the crop was too far advanced and grew too rapidly to be kept pastured off by the pigs, and it was necessary to mow the rye to promote new growth and prevent seed formation. The mowing was done June 10, and conditions were such that a new and more palatable growth started soon afterwards.

On that date also the pigs were weaned and the sows removed from the pasture. The pasture period on rye was terminated July 8. Because of the extremely succulent quality of the forage the gains made by the pigs were low. The supplementary grain consumed was above the average. From the standpoint of grain consumed the pigs in the check lot produced more economical gains than did the pigs on pasture.

In each of the years 1928, 1929, and 1930, precipitation was light and the amount of forage produced was much less than in 1927. In addition to the 15 spring pigs used each year, 2 brood sows were carried on the rye pasture for a period of 28 days in 1929 and 26 days in 1930. The average daily gains made by the pigs on rye pasture were higher in 1928, 1929, and 1930 than in 1927. Also the amount of supplementing grain fed for each 100 pounds of gain was less during the last three years than in 1927, but the pasture pigs each year consumed more grain per unit of gain than did the pigs in the check lot.

Table 34 presents the data obtained in the rye-pasturing experiment.

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TABLE 34.—*Results obtained from pasturing winter rye (1-acre plots) by spring pigs at the Huntley field station, 1927–1930*

Items of comparison	1927	1928	1929	1930
Test begun	May 18	May 14	May 9	May 3
Test closed	July 8	June 26	July 5	June 19
Length of test ... days	51	43	57	47
Pigs pastured ... number	15	15	15	15
Average initial weight ... pounds	21.8	32.0	23.9	19.6
Average final weight ... do	45.9	66.1	74.3	50.6
Average gain ... do	24.1	34.1	50.4	31.0
Average daily gain ... do	.47	.79	.88	.66
Total gain of pigs ... do	362	512	755	465
Weight lost by brood sows ... do	98	----------	123	93
Net gain of pigs [1] ... do	264	512	632	372
Total feed consumed [2] ... do	1,194	2,247	2,409	1,483
Feed per 100 pounds of gain:				
Pasture lot ... do	452	439	381	399
Check lot [3] ... do	372	319	375	332
Corn replaced by 1 acre of pasture ... do	[4]—211	[4]—614	[4]—38	[4]—249
Acre yield of check plots ... bushels	17.4	12.3	9.3	.4

[1] Gain of pigs minus loss of sows.
[2] Corn, self-fed; skim milk, hand fed; total calculated on the basis of 4 pounds of milk equaling 1 pound of corn.
[3] The check lot fed in a dry pen without pasture consisted of 11 pigs in 1927, 10 pigs in 1928, 14 pigs in 1929, and 17 pigs in 1930.
[4] Minus indicates loss.

Each year the pigs have been moved to the acre plot of field peas on the date of closing the pasture period on winter rye. The character of this forage at the time of pasturing varies greatly with the type of season and the length of rye-pasture period. In some years the peas have begun to form seed before the plot was opened for pasturing, while in other seasons it has been necessary to use the plot of peas at an earlier stage of growth in order to provide the pigs with continuous grazing. In 1927 the peas produced a heavy growth of vines and had begun to form seed when the plot was opened to grazing. The gains in weight made by the pigs, though small, were economical when based on the grain consumed. The seasons of 1928, 1929, and 1930 were dry, and the pea forage was not as plentiful as in 1927. In fact, in 1930 the peas dried up before making enough growth to warrant pasturing, and the experiment was omitted for the season. The gains in 1928 and 1929 were somewhat higher than those in 1927. Grain consumed per unit of gain was also higher than in 1927, but less grain was used by the pigs on pasture than by those in the check lot to produce a hundredweight of gain. The data from pasturing peas are summarized in Table 35.

TABLE 35.—*Results obtained from pasturing field peas (1-acre plots) by spring pigs at the Huntley field station, 1927–1930*

Items of comparison	1927	1928	1929	1930
Test begun	July 8	June 26	July 5	[1]
Test closed	Aug. 5	Aug. 2	Aug. 1	----------
Length of test ... days	28	37	27	----------
Pigs pastured ... number	15	15	15	----------
Average initial weight ... pounds	45.9	66.1	70.2	----------
Average final weight ... do	62.7	106.5	104.0	----------
Average gain ... do	16.8	40.4	33.8	----------
Average daily gain ... do	.60	1.09	1.25	----------
Total gain of pigs ... do	252	606	507	----------
Total feed consumed ... do	720	1,964	1,575	----------
Feed per 100 pounds of gain:				
Pasture lot ... do	286	324	311	----------
Check lot ... do	395	331	354	----------
Corn replaced by 1 acre of pasture ... do	275	42	218	----------
Acre yields of check plot ... bushels	19.8	8.0	0	0

[1] Field peas dried up before making sufficient growth for pasturage.

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As a substitute for pea pasture in 1930 the pigs were given the run of one-half acre of alfalfa planted in rows 2 feet apart. They remained on the alfalfa for 42 days, June 19 to July 31, during which time they made an average daily gain of 1.25 pounds each. The shelled corn was equivalent to 254 pounds of grain for each 100 pounds of gain. The check lot of pigs during the same interval gained at the rate of 0.88 pound each per day and required 345 pounds of grain for a hundredweight of gain. The alfalfa pasture had a calculated grain-replacement value of 719 pounds to the acre for the 42-day period.

With the completion of the pasture period on field peas, the practice since 1924 has been to move the spring pigs from the acre of peas first to a combination pasture of Sudan grass and soybeans, one-fourth acre of each, and later to a combination pasture of sorgo and soybeans. The supplementary ration of self-fed shelled corn was continued on these combination pastures. With the exception of 1928, the pigs on Sudan grass-soybean pasture consumed more grain per 100 pounds of gain each year than did the pigs in the check lot. While on sorgo-soybean pasture, however, the pigs, except in 1927, required less grain for each hundredweight of gain than did the check-lot pigs. The data obtained from pasturing pigs on Sudan grass, soybeans, and sorgo are given in Table 36.

TABLE 36.—*Results obtained from grazing Sudan grass-soybeans and sorgo-soybeans mixed pastures (½-acre plots) by spring pigs at the Huntley field station, 1927–1930*

Items of comparison	Sudan grass, soybeans				Sorgo, soybeans		
	1927	1928	1929	1930 [1]	1927	1928	1929
Test begun	Aug. 5	Aug. 2	Aug. 1	July 31	Sept. 2	Aug. 21	Aug. 20
Test closed	Sept. 2	Aug. 21	Aug. 20	Sept. 11	Sept. 16	Sept. 11	Sept. 9
Length of test ... days	28	19	19	42	14	21	20
Pigs pastured ... number	15	15	15	13	15	15	[2] 15
Average initial weight ... pounds	62.7	106.5	104.0	100.8	94.0	130.7	124.0
Average final weight ... do	94.0	130.7	124.0	153.5	113.8	160.1	152.4
Average gain ... do	31.3	24.2	20.0	52.8	19.8	29.4	28.8
Average daily gain ... do	1.12	1.27	1.05	1.26	1.41	1.40	1.45
Total gain of pigs ... do	469	363	300	686	297	441	420
Total feed consumed ... do	1,471	1,117	1,423	2,880	1,122	1,784	1,463
Feed per 100 pounds of gain:							
Pasture lot ... pounds	314	308	474	420	378	405	348
Check lot ... do	310	400	357	407	336	434	402
Corn replaced by 1 acre of pasture ... pounds	−38	668	−702	−89	−249	256	454
Acre yields [3] of check plots:							
Sudan grass ... pounds	4,800	1,104	1,350	620	----------	----------	----------
Soybeans ... do	13,870	712	1,250	0	----------	----------	----------
Sorgo ... do	----------	----------	----------	----------	12,190	1,812	4,150
Soybeans ... do	----------	----------	----------	----------	13,870	712	2,750

[1] Because of drought and the poor quality of the forage in 1930 the 2 pastures were grazed as 1 plot rather than separately, as was done in 1927, 1928, and 1929. The combined results from grazing the Sudan grass-soybean pasture and the sorgo-soybean pasture are given in this column.
[2] Only 14 pigs after September 2. Gains and feed of 15th pig included to nearest weighing date, Aug. 29.
[3] Air dry.

From the sorgo-soybean pasture the spring pigs have been taken to a 1-acre plot of Northwestern Dent corn in the pasture rotation. At that date the corn has usually been mature or nearly so, and no grain supplement has been fed with it. In some seasons, however, the pigs have had access to alfalfa hay or skim milk to balance the ration while on corn. The length of the pasture period on corn has varied greatly, depending upon the amount produced. In 1930, because of drought, no corn was produced, and that phase of the experiment was omitted. Small crops of corn were produced in 1928 and 1929, and the pasture

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periods for those years were 7 days and 3 days, respectively; whereas in 1927 sufficient corn was produced to supply the pigs for 28 days. If the amount of grain consumed by the pigs on the pastured corn plot is calculated on the basis of the yields of corn from the check plot, the hogs in the dry pen have required less corn to produce a hundred pounds of gain than have the hogs on corn pasture. A summary of the corn-pasturing experiments is presented in Table 37.

TABLE 37.—*Results obtained from harvesting corn (1-acre plots) by spring pigs at the Huntley field station, 1927–1930*

Items of comparison	1927	1928	1929	1930 [1]
Test begun	Sept. 16	Sept. 11	Sept. 9	
Test closed	Oct. 14	Sept. 18	Sept. 12	
Length of test ... days	28	7	3	
Pigs pastured ... number	15	15	15	
Average initial weight ... pounds	113.8	160.1	152.4	
Average final weight ... do	152.0	163.9	147.8	
Average gain ... do	38.2	3.8	−4.6	
Average daily gain ... do	1.36	.54	−1.53	
Total gain of pigs ... do	573	57	−69	
Total feed consumed [2] ... do	2,744	680	258	
Feed consumed per 100 pounds of gain:				
Pasture lot ... pounds	479	1,193		
Check lot ... do	457	359	243	
Acre yields of check plots ... bushels	49.0	11.2	3.6	0

[1] Corn dried up before producing grain, and the plot was not harvested by pigs.
[2] Feed consumed based on yield of check plot in 1927. In 1928 the corn was supplemented with skim milk, and the total feed was calculated from the yield of corn on the check plot plus the skim milk fed (4 pounds of milk equal to 1 pound of corn).

Plots of Success barley 1 acre in area were grown and harvested in both the pastured and unpastured rotations each year of the four here reviewed. The grain yields of barley from the pastured rotation exceeded those of the unpastured rotation in 1928 and 1929. Heavier yields of straw were obtained from the pastured than from the unpastured rotation in 1927 and 1928. No grain or straw was produced on either plot in 1930. The yield data from both plots are compared in Table 38.

TABLE 38.—*Annual acre yields of barley straw and grain obtained from plots in similar rotations in one of which all crops but barley were pastured by hogs and in the other all crops were harvested by machinery, at the Huntley field station, 1927–1930*

Rotation treatment	1927		1928		1929		1930	
	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
	Pounds	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Bushels*	*Pounds*	*Bushels*
Pastured	2,810	29.4	776	21.1	1,099	15.6	0	0
Harvested	2,800	33.8	323	9.1	1,160	10.9	0	0

PERENNIAL-CROP PASTURES

The perennial crops have been represented in the dry-land pasturing experiments by two plots each of alfalfa and bromegrass. One plot of each crop has been grown in rows 2 feet apart, and the other has been close-seeded in drills 6 inches apart. During the years covered by this report ½-acre plots of each crop and seeding method were pastured by fall pigs, which, in addition to the forage, were hand-fed a daily ration of shelled corn equal to 3 per cent of the live weights of the animals. Throughout the period that the pigs were on pasture a check lot of similar pigs was given a ration of skim milk and self-fed

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corn in a dry pen without pasture. The length of time the hogs remained on pasture each year was governed by the growth of the animals as well as by the condition of the forage, the object being to keep the hogs on pasture if possible until they had reached a marketable weight of 200 pounds or more. The highest average daily gains made by any of the fall pigs on perennial pastures were on row alfalfa and close-drilled alfalfa in 1928. The hogs have usually made more rapid gains on alfalfa pasture than on bromegrass; and from the viewpoint of supplementary grain consumed, the alfalfa pastures have also been the most economical. With one exception, from 1927 to 1930, the hogs on pasture have required less supplementary grain to produce 100 pounds of gain than have the hogs in the check lot. The results obtained by pasturing alfalfa and bromegrass by fall pigs are given in Tables 39 and 40.

TABLE 39.—*Results obtained from pasturing by fall pigs ½-acre plots of alfalfa sown in rows 2 feet apart and of alfalfa close-drilled, at the Huntley field station, 1927–1930*

Items of comparison	Alfalfa in rows				Alfalfa close-drilled			
	1927	1928	1929	1930	1927	1928	1929	1930
Test begun	May 7	May 14	May 17	May 16	May 7	May 14	May 17	May 16
Test closed	July 8	June 26	July 5	June 18	July 8	June 26	July 5	June 18
Length of test...days	62	43	49	33	62	43	49	33
Pigs pastured ...number	3	3	3	3	3	3	3	3
Average initial weight ...pounds	132.0	139.0	152.7	162.7	132.3	138.0	142.7	161.0
Average final weight ...pounds	225.0	210.3	221.0	215.0	228.0	209.0	217.3	206.7
Average gain...do	93.0	71.3	68.3	52.3	95.7	71.0	74.6	45.7
Average daily gain ...pounds	1.50	1.66	1.39	1.58	1.54	1.65	1.52	1.38
Total gain...do	280	214	205	157	287	213	224	137
Total feed consumed ...pounds	988	700	843	547	1,002	700	828	527
Feed per 100 pounds of gain:								
Pasture lot...pounds	353	327	411	348	349	329	370	385
Check lot...do	398	428	451	538	398	428	451	538
Corn replaced by 1 acre of pasture...pounds	252	454	164	597	230	422	363	419

TABLE 40.—*Results obtained from pasturing by fall pigs ½-acre plots of bromegrass sown in rows 2 feet apart and of bromegrass close-drilled, at the Huntley field station, 1927–1930*

Items of comparison	Bromegrass in rows				Bromegrass close-drilled			
	1927	1928	1929	1930	1927	1928	1929	1930
Test begun	May 7	May 14	May 17	May 16	May 7	May 14	May 17	May 16
Test closed	July 8	June 26	July 5	June 18	July 8	June 26	July 5	June 18
Length of test...days	62	43	49	33	62	43	49	33
Pigs pastured ...number	3	3	3	3	3	3	3	3
Average initial weight ...pounds	132.0	139.3	150.3	159.3	131.7	138.7	151.0	158.0
Average final weight ...pounds	209.3	192.7	221.7	205.3	213.3	193.7	221.3	199.7
Average gain...do	77.3	53.4	71.4	46.0	81.6	55.0	70.3	41.7
Average daily gain ...pounds	1.25	1.24	1.46	1.39	1.32	1.28	1.43	1.26
Total gain...do	232	160	214	138	245	165	211	125
Total feed consumed ...pounds	960	658	843	527	960	672	843	527
Feed per 100 pounds of gain:								
Pasture lot...pounds	414	411	394	382	392	407	400	422
Check lot...do	398	428	451	538	398	428	451	538
Corn replaced by 1 acre of pasture...pounds	−74.0	54.0	244	431	29.0	69.0	215	290

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EXPERIMENTS WITH DAIRY CATTLE[6]

A herd of registered Holstein-Friesian cattle is maintained by the Bureau of Dairy Industry at the Huntley field station, and cooperative experiments are carried on in breeding and feeding dairy cows and in grazing irrigated pastures. Feeding tests comparing the economy of production have been completed in which groups of cows were fed rations consisting of roughage alone, roughage and a full feed of grain, and roughage and a limited amount of grain. An experiment was conducted to determine the adaptability of alfalfa for silage. Experiments to determine the effect of alfalfa hay as a complete ration for dairy cows are being carried on. Experiments in grazing irrigated pastures have included tests of the carrying capacity of various pasture-grass mixtures and sweetclover. The effect of top-dressing pastures with manures and phosphates is being studied. The breeding experiments deal largely with establishing a strain of cattle pure in their inheritance for high milk and butterfat production. This is to be accomplished through the continued use of proved sires, i. e., sires that are known to transmit high production to their offspring. Dairymen in the neighborhood of the station cooperate in proving these sires by using them in their herds and by keeping production records of their cows and the daughters of these sires.

PROVED-SIRE TESTS

The proving of sires was started in 1918, and during the period 1918 to 1930 a total of 73 sires were placed for proving. This total includes the sires used at the station as well as those placed in cooperators' herds throughout the States of Montana and Wyoming. At the time of writing this report 38 sires were being proved by 67 cooperators in the country adjacent to the station. Several sires have been proved during the last few years and have gone to head herds in other experiment stations or colleges where the proved-sire experiment is being carried on. The men using these sires agree to retain the heifers sired by the bulls and to furnish production records of the dams as well as of the heifers. During 1930 a total of 1,127 cows were tested for milk and butterfat production, each cow's record being kept on file and a written report sent to each cooperator. Up to the end of 1930 a total of 1,360 heifers had been sired by station bulls. Of this number, 1,109 are still living or have made records in present cooperators' herds or those of former cooperators.

Table 41 contains a comparison of the records of 302 daughters sired by 31 station bulls in cooperators' herds, with records of the dams of those daughters. The list of sires includes all bulls having two or more first-generation daughters that have completed at least 1-year's lactation period. Of the daughters, 232 exceeded the production of their dams in milk, 161 in percentage of butterfat, and 240 in total amount of butterfat.

[6] Report prepared by D. V. Kopland. The dairy work is conducted under the supervision of the Division of Dairy Cattle Breeding, Feeding, and Management, Bureau of Dairy Industry.

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TABLE 41.—*Records of first-generation daughters of bulls having two or more such daughters with records, compared with the records of the dams of those daughters*

[All records calculated to a mature basis]

Sire No.	Daughters					Dams					Increase or decrease		
	Cows	Records	Milk	Butterfat		Cows	Records	Milk	Butterfat		Milk	Butterfat	
	Number	*Number*	*Pounds*	*P. ct.*	*Pounds*	*Number*	*Number*	*Pounds*	*P. ct.*	*Pounds*	*Pounds*	*P. ct.*	*Pounds*
H-104	[1] 22	25	16,351.2	3.55	581.19	[1] 22	37	15,330.8	3.44	527.38	1,020.4	0.11	53.81
H-105	13	19	10,265.8	3.67	377.08	13	32	10,030.1	3.64	365.19	235.7	.03	11.89
H-107	20	37	11,291.9	3.81	430.70	20	47	9,154.9	3.71	338.90	2,137.0	.10	91.80
H-109	12	28	10,372.1	3.64	377.60	12	15	6,870.6	3.81	261.82	3,501.5	−.17	115.78
H-111	13	18	9,804.9	3.55	348.19	13	35	8,049.9	3.46	278.30	1,755.0	.09	69.89
H-112	27	54	12,129.9	3.64	441.76	27	62	9,047.0	3.68	333.77	3,082.9	−.04	107.99
H-113	3	7	10,818.9	3.48	376.24	3	14	9,834.8	3.38	332.74	984.1	.10	43.50
H-114	8	10	8,410.5	3.90	328.09	8	22	7,365.9	3.64	268.71	1,044.6	.26	59.38
H-115	14	17	11,275.3	3.54	399.48	14	42	8,689.3	3.56	309.36	2,586.0	−.02	90.12
H-116	3	3	9,978.0	3.76	375.22	3	8	7,811.8	3.54	277.66	2,166.2	.22	97.56
H-117	7	9	8,956.6	3.79	339.65	7	24	10,778.4	3.55	384.48	−1,821.8	.24	−44.83
H-118	9	12	11,298.7	3.63	410.74	9	14	9,398.2	3.69	347.56	1,900.5	−.06	63.18
H-120	10	23	11,680.3	3.45	403.76	10	23	8,403.4	3.59	301.84	3,276.9	−.14	101.92
H-121	4	7	14,598.6	3.58	524.96	4	13	12,633.4	3.63	459.50	1,965.2	−.05	65.46
H-123	12	20	9,467.9	3.48	329.58	12	21	7,206.2	3.36	242.41	2,261.7	.12	87.17
H-126	10	13	10,434.5	3.70	386.13	10	32	9,804.5	3.65	357.76	630.0	.05	28.37
H-127	9	11	9,623.6	3.53	340.42	9	19	7,400.2	3.70	273.92	2,223.4	−.17	66.50
H-130	5	5	10,413.2	3.57	372.28	5	9	8,324.6	3.88	323.68	2,088.6	−.31	48.60
H-131	6	7	9,322.7	3.80	354.55	6	12	7,636.3	3.59	274.11	1,686.4	.21	80.44
H-132	3	3	14,957.0	3.70	554.46	3	6	11,462.4	3.57	409.21	3,494.6	.13	145.25
H-135	3	3	11,549.1	3.48	402.11	3	5	10,406.8	3.39	353.66	1,142.3	.09	48.45
H-143	4	4	12,310.4	3.53	434.62	4	9	9,713.7	3.47	337.18	2,596.7	.06	97.44
H-257	19	31	10,334.0	3.50	361.38	19	47	8,601.9	3.49	299.83	1,732.1	.01	61.54
A-104	3	3	10,739.3	3.50	375.92	3	10	8,739.8	3.78	330.34	1,999.5	−.28	45.58
A-105	[1] 23	36	14,138.9	3.61	511.03	[1] 23	55	13,543.4	3.53	478.27	595.5	.08	32.76
A-107	15	26	9,734.3	3.69	359.59	15	42	8,542.0	3.67	313.64	1,192.3	.02	45.95
A-108	7	24	8,900.9	3.38	302.27	7	17	9,800.6	3.13	306.78	−899.7	.25	−4.51
A-109	11	26	9,911.3	3.47	344.37	11	25	9,230.2	3.44	317.66	681.1	.03	26.71
A-110	2	2	12,381.0	3.57	442.49	2	4	9,127.1	3.78	345.55	3,253.9	−.21	96.95
A-119	2	4	10,984.0	3.91	430.23	2	4	8,622.3	3.27	282.01	2,361.7	.64	148.22
A-121	3	3	11,787.3	3.48	411.27	3	3	8,193.3	3.81	312.50	3,594.0	−.33	98.77
Average	9.7	15.8	11,398.0	3.61	411.17	9.7	22.8	9,594.4	3.57	342.44	1,757.0	.04	67.15

[1] Official records made in the Huntley station herd.

Six of the bulls in the comparison (A–107, A–108, A–109, A–110, A–119, and A–121) were sired by the bull Colantha Pontiac Hero. These bulls had a total of 40 daughters with completed records, which, when compared with those of their dams, show increases of 19.02 per cent in milk, 2.28 per cent in percentage of butterfat, and 21.94 per cent in pounds of butterfat. Only one of these six sons shows a loss in transmitting milk-producing ability, comparing the total records of the daughters with their dams.

Five of the bulls (H–130, H–131, H–132, H–135, and H–141) were sired by Friend Ona Hartog Korndyke (A–105) and have a total of 21 daughters with completed records which show, in comparison with those of their dams, increases of 23.15 per cent in milk, 1.40 per cent in butterfat test, and 24.74 per cent in pounds of butterfat. Not one of these five sires shows an individual decrease in total milk and fat production of his daughters. In most instances the daughters of these bulls are from dams whose sires were by a station bull.

The daughters of all but 1 of the 15 sons (H–107 to H–127, inclusive) of Mapleside King Paul (H–104), the first proved sire used in the breeding work, show a distinct increase in milk and fat production. (Figs. 5 and 6.) The daughters of the one bull (H–117) that have a decrease in production were not given a fair chance as heifers, in that

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they were bred and freshened too young and in most instances were undersized. It is hoped that their records as mature cows will be

FIGURE 5.—Holstein bull Mapleside King Paul 181023, a proved sire. Twenty-two daughters of this sire averaged 646 pounds of butterfat in a year as compared with an average production of 571 pounds butterfat for their dams. (Records calculated to a mature basis)

made under conditions more comparable with those under which the dams were tested. The 161 daughters of these 15 sires gave an increase

FIGURE 6.—Holstein cow Duchess Sadie Korndyke 764141, a daughter of Mapleside King Paul, having a yearly production as a 7-year-old of 22,611 pounds of milk and 821.9 pounds of butterfat

in production over their dams amounting to 20.92 per cent in milk, 0.8 per cent in percentage of butterfat, and 21.89 per cent in pounds of butterfat.

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CARRYING CAPACITY OF PASTURE

In 1916 a tame-grass pasture was started, composed of the following grasses: Kentucky bluegrass, meadow fescue, orchard grass, smooth bromegrass, alsike clover, and white clover. This mixture was seeded at the rate of 24 pounds of seed per acre.

An experiment was carried on from 1919 to 1930 to determine the number of dairy cattle in milk that an acre of irrigated tame-grass pasture would support throughout the grazing season without supplemental feed. It was necessary, however, during several of the seasons to supply additional feed in the form of alfalfa hay or green-cut crops such as corn.

The cattle used in the experiment were, for the most part, registered Holstein-Friesian cows. Several grade cows, however, were used during the seasons of 1919 and 1920. The cows were generally medium producers, although at times it was necessary to use dry cows so as to insure proper grazing. In these instances the pasture received credit for only the number of days grazed by the dry cows and a credit for gain or loss in weight while these cows grazed. A sufficient number of cows were kept on the pasture throughout the grazing season to assure complete use of all available pasture without subjecting the cattle to a shortage of food.

It was necessary at times to remove all cows from the pasture during stormy weather. During these intervals the cows were fed alfalfa hay or other supplemental feeds. Daily milk weights were taken, and butterfat tests were conducted two days in each seven. The pasture was top-dressed each year with 12 loads of barnyard manure and harrowed in the spring to distribute the previous year's droppings.

Table 42 contains a detailed report of this experiment for the years 1927 to 1930 and the average results for the 12-year period 1919 to 1930.

TABLE 42.—*Results of experiment to determine the maximum carrying capacity of 1 acre of irrigated tame-grass pasture for dairy cows at the Huntley field station, 1927–1930, and averages for the period 1919–1930*

Items of comparison	1927	1928	1929	1930	12-year average, 1919–1930
Average daily number of cows per acre	2.73	1.99	1.92	1.92	2.15
Length of grazing season ... days	138	142	133	160	139.8
Cows on pasture ... do	138	142	133	147	136
Cows off pasture ... do	0	0	0	13	.27
Total cow days per acre ... do	377	283	256	286.5	298
Green corn fed cows on pasture ... pounds	0	0	0	0	154
Alfalfa hay fed cows:					
On pasture ... do	801	613	0	0	724.5
Off pasture ... do	0	0	0	13	107.5
Grazing period of cows on outside pasture ... days	0	0	0	0	1.9
Average weight per cow per season ... pounds	1,388	1,316	1,327.8	1,498.4	1,261.3
Average gain or loss in weight per cow per season ... pounds	223	217	−77.1	8.6	83.6
Production per acre:					
Milk ... do	6,180	6,529	7,304	6,320	6,960.4
Butterfat ... do	232.7	240.2	274.9	236.7	264.9

An experiment to determine the carrying capacity of an acre of sweetclover as a pasture was carried on during 1927, 1928, and 1929. This pasture was handled in nearly all respects like the tame-grass pasture. The cows were average producers as a whole,

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and occasionally dry cows were used to keep the pasture properly grazed. In maintaining the sweetclover pasture a new seeding was made each year. Only the second season's growth was pastured. Both the yellow-flowered and white-flowered varieties were used, and judging from observations made during the grazing season, the cattle seemed to prefer the yellow-flowered variety. However, while the cattle gradually accustomed themselves to the sweetclover, they did not seem to relish it at any time. Table 43 contains the data for the 3-year period.

TABLE 43.—*Results of experiment to determine the maximum carrying capacity of 1 acre of irrigated sweetclover pasture for dairy cows at the Huntley field station, 1927–1929*

Items of comparison	1927	1928	1929	Average
Length of grazing season ... days	111	105	110	108.6
Cows on pasture ... do	96	105	110	103.6
Cows off pasture ... do	15	0	0	5
Total cow days per acre ... do	174.4	163.0	162.2	166.5
Average daily number of cows per acre	1.57	1.55	1.47	1.53
Grazing period of cows on outside pasture ... days	12	0	0	4
Alfalfa hay fed cows:				
On pasture ... pounds	94.5	0	0	31.5
Off pasture ... do	208.2	0	0	69.4
Average weight per cow per season ... do	1,354.0	1,174.0	1,437.9	1,321.9
Average gain or loss in weight per acre per season ... do	−108.2	−244.7	−233.5	−195.5
Production per acre:				
Milk ... do	4,942.3	3,218.4	2,448.1	3,536.3
Butterfat ... do	197.8	125.9	95.38	139.69
Skim milk ... do	4,377.2	2,858.7	2,352.72	3,196.2

FEEDING EXPERIMENTS

EFFECT OF PLANE OF FEEDING ON MILK PRODUCTION

Experiments were conducted to obtain information as to the relative economy of milk production by cows fed on three planes termed "roughage," "limited grain," and "full grain." The first group of cows received all the roughage that they would consume, such as corn silage, alfalfa hay, and root crops in season, and in addition were placed on irrigated pasture during the grazing season. Cows in the other groups were given all the roughage that they would consume and in addition the limited-grain cows received 1 pound of grain to every 6 pounds of milk produced and the full-grain cows received twice this amount of grain. The grain mixture used in the rations of both the full-grain and limited-grain groups was composed of 2 parts of mill feed, 2 parts of ground oats, 2 parts of ground corn, and 1 part of linseed meal. Ten cows were used in the experiment, each cow completing a lactation period on each of the three planes at one time or another during the 7-year period 1919–1926. As a rule, the cows were placed on the full-grain ration first in order that an index of their producing ability might be obtained as soon as possible for inheritance studies. Their records were made under official-test conditions, the cows being milked three times a day. Table 44 contains data from this experiment.

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TABLE 44.—*Comparison of the effect of three planes of feeding on milk production by 10 cows at the Huntley field station*

Items of comparison	Average for cows fed—		
	Roughage	Limited grain	Full grain
Age of cows ... years	6½	7	4⅙
Ration:			
Alfalfa hay ... pounds	6, 376	5, 978	6, 782
Silage ... do	11, 234	12, 076	8, 501
Beet pulp ... do	65	2	244
Beets ... do	1, 345	527	2, 258
Pasture ... days	132	138	120
Grain ... pounds	----------	2, 710	5, 266
Weight of cows [1] ... do	1, 240. 2	1, 330. 6	1, 237. 7
Gain in weight during test ... do	30	108	180
Dry period prior to test ... days	78	55	56
Grain fed while cows were dry ... pounds	132	111	186
Calf-carrying period ... days	175	155	188
Milk produced:			
Actual ... pounds	13, 295. 2	16, 407. 2	15, 793. 3
Calculated to maturity [2] ... do	13, 656. 5	16, 648. 6	17, 851. 5
Butterfat produced:			
Percentage of milk	3. 49	3. 51	3. 45
Weight, actual ... pounds	464. 11	576. 45	544. 43
Weight, calculated to maturity [2] ... do	478. 00	584. 10	619. 90
Value of butterfat and skim milk [3] ... dollars	252. 07	312. 76	295. 70
Cost of feed exclusive of pasture [4] ... do	65. 13	105. 06	150. 46
Cost of feed including pasture [5] ... do	91. 49	127. 15	163. 64
Returns over cost of feed ... do	160. 58	185. 61	132. 06

[1] The average weight of the group was based on an average weight of each individual in the group. The average weight of the individual was determined by averaging her monthly weights throughout the testing period.

[2] Individual records in each group when made by an animal in heifer form are calculated to represent her production at mature age.

[3] Computed in the following values: Butterfat, 44 cents per pound; skim milk, 40 cents per 100 pounds.

[4] Computed on the following values per ton: Grain, $32; alfalfa hay, $10; silage, $5; dried beet pulp, $35; beets, $6.

[5] Cost of pasture per day: For cows on roughage alone, 20 cents; on limited grain, 16 cents; on full grain, 11 cents.

In comparing the results it is noted that the roughage group gained 30 pounds in body weight, indicating that this group consumed a sufficient amount of nutrients to meet the demands of production and the requirements of body maintenance. However, 3 individuals in this group were not mature, in that they were between 4 and 5 years of age. Whether the lack of maturity in these instances is a factor of importance in considering the loss or gain in body weight is not known. On the other hand, the limited-grain group gained 108 pounds and the full-grain group gained 180 pounds. The limited-grain group contained 1 individual under 4 years of age at the beginning of the trial, whereas the full-grain group contained 7. If considerable importance is attached to the factor of age, it is apparent that the latter two groups received more nutrients than required, especially the full-grain group. From an economic standpoint the roughage group returned an income over the cost of feed of $160.58, the limited-grain group $185.61, and the full-grain group $132.06. It is apparent that the full-grain group wasted feed.

It appears from this experiment that under conditions at this station an abundance of first-quality roughage is a prime requisite for economical milk and butterfat production and that a light supplemental feed of grain may be advantageously supplied when cows of better than average production are maintained.

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ALFALFA-MOLASSES SILAGE

An experiment to determine the desirability of a legume silage for dairy cows was conducted in 1928 and 1929. Fresh-cut alfalfa was ensiled and was moistened with sugar-beet molasses at the rate of 1 part of molasses to 20 parts of alfalfa by weight to provide the necessary sugars for fermentation. This produced a grade of silage of good keeping quality, possessing a characteristic although not objectionable odor. The freshly mowed alfalfa was hauled to the silage cutter and run into the silo in the same manner that corn is handled. The molasses was diluted with warm water and thoroughly sprinkled over the alfalfa as it went into the silo.

Two fresh cows were used in the experiment in 1928 and were fed corn silage and alfalfa-molasses silage ad libitum over a period of 139 days, from July 15 to November 30. No other supplemental feed such as grain or hay was offered. One of the cows, H–48, freshened on July 12 and produced 49.3 pounds of milk on July 15. On the concluding day of the period she produced 26.8 pounds of milk. Her decline in production was the most rapid during the first 30 days, the yield having dropped to 35.4 pounds on August 15. From then on throughout the balance of the trial she maintained a fairly constant milk flow.

Her stable mate, H–49, freshened on July 30 and produced 34.1 pounds of milk on August 1. The decline in production was not unusual, although it might have been anticipated that she would have produced more milk to start with, had she been receiving feed of a different character prior to freshening, as did H–48.

During the first 11 days of the trial the cows consumed on an average 25.3 pounds of alfalfa-molasses silage and 19.3 pounds of corn silage. On July 25 the corn silage became exhausted so that alfalfa-molasses silage alone was fed from that date up to and including August 29. In this period there was an average daily consumption of 45 pounds of alfalfa-molasses silage. Cow H–48 consumed as high as 60 pounds of this silage in one day, while H–49 consumed as much as 59 pounds in one day. During the interval from September 8 to 21 the alfalfa-molasses silage was discontinued, and corn silage alone was fed. H–48 consumed as high as 69 pounds and H–49, 63 pounds in one day. On September 22 alfalfa-molasses silage was again added to the ration, and both cows were fed ad libitum throughout the remainder of the trial. During this period of 70 days there was an average consumption of 46.8 pounds of corn silage and 21 pounds of alfalfa-molasses silage. The daily consumption by the individuals varied greatly, ranging from 80 pounds of corn silage and 19 pounds of alfalfa-molasses silage on October 27 to 20 pounds of corn silage and 55 pounds of alfalfa-molasses silage on October 15 in the case of H–48. H–49 also showed a similar variation, consuming 70 pounds of corn silage and 17 pounds of alfalfa-molasses silage on October 27, while on October 23 she consumed 20 pounds of corn silage and 50 pounds of alfalfa-molasses silage. During the 139 days cow H–48 lost 130 pounds in body weight, while H–49 lost 421 pounds.

The addition of 5 pounds of straw to their ration did not seem to satisfy a craving exhibited by the cows throughout the trial. They refused to eat this additional roughage after several days. On the other hand, an alfalfa-hay supplement of 5 pounds daily per cow was readily eaten when offered in a feeding trial to two cows in milk

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during a period of 43 days. In this phase of the feeding trial corn silage and alfalfa-molasses silage were offered ad libitum with an allowance of 5 pounds of alfalfa hay per cow per day. A gradual decline in milk production was observed, the decline, however, being about normal, in that no sharp drop occurred with either cow. The cows in this instance were milking 50 pounds each at the start of the trial and 43 days later were producing within from 5 to 8 pounds of their first day's production. Their average daily consumption over this period was 30.5 pounds of corn silage and 10.5 pounds of the alfalfa-molasses silage and 5 pounds of alfalfa hay. One of the cows ate considerably more of the alfalfa-molasses silage than did the other, the one consuming 664 pounds and the other 236 pounds. One cow lost 169 pounds in body weight, and the other lost 167 pounds in the 43 days of the trial.

Conclusions drawn from these two trials are that large amounts of legume silage such as alfalfa-molasses silage will be consumed by milk cows provided their ration is restricted in variety and amount of other feeds. The individual cow varies considerably in her appetite for alfalfa-molasses silage. Alfalfa as a silage may be warranted when a succulent feed is desired in localities where corn silage can not be profitably produced. It may be profitably fed as a supplement to other roughages in the ration. Considerable loss in weight can be expected if alfalfa-molasses silage forms a large part of the ration for cows giving considerable quantities of milk.

FEEDING COWS ON ALFALFA HAY ALONE

An experiment is in progress to determine the effect on production, health, and economy of production of cows fed for entire lactation periods or longer on alfalfa hay alone. Some of the cows in this experiment have completed records on one or more of the three planes of feeding in an experiment previously mentioned (p. 44). Those records, together with the fact that alfalfa hay is plentiful, should make the results very significant for this locality.

Results so far indicate that cows will consume large quantities of hay and will produce sufficient quantities of milk and butterfat to make their production very economical. Considerable body weight is lost early in the lactation period, but this weight is gradually regained later in the lactation period.

ORNAMENTAL TREES AND SHRUBS[7]

Since becoming established, the trees and ornamental shrubs on the station and in the 4-acre tract known as Project Park, adjoining the station grounds, have attracted attention from the standpoint of beautifying the farmstead as well as providing shade, windbreaks, and screens.

The first plantings were made in 1914 around the station buildings. These plantings have been extended from time to time as the station grounds have expanded. The park was planted in 1917. The nursery stock for the various plantings on the station and in the park were obtained from dealers and from the United States Northern Great Plains Field Station at Mandan, N. Dak. The plantings have been given ordinary care in cultivation, pruning, and irrigating and provide a practical demonstration as to what may be done in a few years' time with this material on the farms of the Huntley project.

[7] Report prepared by A. E. Seamans.

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The trees and shrubs used in the various plantings are given in the following list:

TREES

Common name	Scientific name
Ash, green	*Fraxinus lanceolata.*
Boxelder	*Acer negundo.*
Cottonwood, northern	*Populus monilifera.*
Elm, American	*Ulmus americana.*
Elm, Chinese	*Ulmus pumila.*
Linden, American	*Tilia americana.*
Maple, Norway	*Acer platanoides.*
Pine, western yellow	*Pinus ponderosa.*
Plum, American	*Prunus americana.*
Cottonwood, Carolina	*Populus angulata.*
Poplar, northwest	*Populus* sp.
Poplar, silver	*Populus alba nivea.*
Russian-olive	*Elaeagnus angustifolia.*
Spruce, Black Hills	*Picea glauca albertiana.*
Walnut, black	*Juglans nigra.*
Willow, diamond	*Salix mackenzieana.*
Willow, Russian golden	*Salix vitellina aurea.*
Willow, laurel	*Salix pentandra.*

SHRUBS

Barberry, Japanese	*Berberis thunbergii.*
Buckthorn, common	*Rhamnus cathartica.*
Cranberrybush, European	*Viburnum opulus.*
Currant, golden	*Ribes* sp.
Currant, alpine	*Do.*
Dogwood, coral	*Cornus alba sibirica.*
Elder, golden	*Sambucus* sp.
False-spirea, Ural	*Sorbaria sorbifolia.*
Honeysuckle, Tatarian	*Lonicera tatarica.*
Lilac, common	*Syringa vulgaris.*
Lilac, Persian	*Syringa persica.*
Lilac, Japanese tree	*Syringa japonica.*
Mulberry, Russian	*Morus alba tatarica.*
Ninebark	*Opulaster opulifolius.*
Pea-tree, Siberian	*Caragana arborescens.*
Spirea, Vanhoutte	*Spiraea vanhouttei.*
Spirea, Anthony Waterer	*Spiraea* sp.
Snowball, common	*Viburnum opulus sterile.*
Mockorange	*Philadelphus grandiflorus.*

Except for occasional tip killing in severe seasons, all species of trees used have been proved hardy after becoming established. The elms, poplars, boxelders, and willows have made the most rapid growth, while the ash, American linden, maple, plum, and Russian-olive have developed more slowly. Pine and spruce have not only been difficult to transplant successfully but have grown very slowly.

Under irrigation the elms, particularly the Chinese, and in some instances the boxelders, have made a top-heavy growth and many of the trees have been damaged during windstorms by the splitting off of large limbs. The Chinese elm has been free from insect pests, but a number of the trees have been injured by a canker which has entered the tree through pruning or accidental wounds. The American elm has frequently been found infested with aphids but apparently has been free from disease.

The poplars have usually developed into large, well-formed trees more quickly than have the other species, but because of the attacks of borers and certain bark diseases they have proved to be rather short lived.

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Aphids, the "boxelder bug," and the larvae of various moths have commonly been found in the boxelder trees in these plantings, but have seemingly done little injury to the trees. Aside from occasional breaking off of top-heavy limbs during severe winds, this tree has proved to be well adapted to the climatic and soil conditions of this locality.

Willows have generally made a rapid and dense growth, especially when planted along the banks of canals and irrigation ditches. When planted closely, the willows have served well as screens and windbreaks. All species have been relatively free from diseases and insect pests.

No serious disease has yet been found on the ash, American linden, maple, or plum. Various larvae have been found on these trees at times, and the foliage of all has been more or less mutilated by leaf-cutter bees during the summer.

The Russian-olive when grown as a tree has shown no injury from insect pests and only slight evidence of disease. In a Russian-olive hedge maintained at the station for several years a number of the plants were killed by crown gall.

A few black walnut trees were planted on the station in 1911, and in 1919 a small number of the same species were set out in Project Park. The older trees have made a very satisfactory growth and for several years have borne fair crops of nuts. The trees planted in 1919 died three or four years later from injuries rather than because of a lack of hardiness. The black walnut has so far been free from disease and serious insect pests.

Numerous conifers have been planted at the station from time to time, but in most cases the percentage of survival has been low. Nursery stock of spruce dug and shipped with a ball of earth surrounding the roots has become established more quickly and the loss has been less than with stock that had the earth removed from the roots at the time it was dug or in preparation for shipment. The growth of pine and spruce has been slow, but the trees appear to be free from troublesome insects and disease.

Practically all of the shrubs listed as being grown at Huntley have shown winter injury in some seasons, but in no case has such injury been severe enough to cause the death of the plant. Perhaps the least susceptible to winter injury have been the cranberrybush, Siberian pea-tree, and dogwood. Spirea, barberry, currant, honeysuckle, lilac, buckthorn, and snowball have frequently suffered the killing back of tips and young shoots during the winter or early spring. The golden elder and Russian mulberry have killed back heavily nearly every winter, and during severe seasons practically all of the aboveground growth has been killed. These species grow rapidly, however, and by midsummer have usually become reestablished.

With the exception of an occasional infestation of tent caterpillars on the currant and aphids on the snowball, the shrubs have been practically free from injurious insect pests. Mildew and leaf spot on both species of currant have so far been the only diseases that have required treatment.

Practically all of the shrubs have been used in group plantings on lawns, around the station buildings, and in windbreaks associated with trees, although a few specimens of Vanhoutte spirea and lilac have been planted singly on the station grounds. Buckthorn and Siberian pea-tree have each been grown in ornamental hedges and have proved to be very effective when used for this purpose.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

PRELIMINARY YIELD TABLES FOR SECOND-GROWTH STANDS IN THE CALIFORNIA PINE REGION

By DUNCAN DUNNING, *Silviculturist*, and L. H. REINEKE, *Associate Silviculturist, California Forest and Range Experiment Station,*[1] *Branch of Research, Forest Service*

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INTRODUCTION

The conifer forests of the California mountains are among the most valuable in North America. The character of the tree species forming the stands, the large dimensions attained by individual trees, the heavy yields, the extensive area occupied, and its comparative accessibility contribute to high values.

These high values have been hitherto associated almost entirely with virgin or old-growth stands. In recent years, however, second growth has begun to assume importance in the general scheme of forest economy. It is true that second growth has a present-utilization value in only rare instances of minor importance—the greater values still lie in the future; but for this very reason it has become desirable and is, indeed, becoming increasingly necessary to be able to forecast these values as accurately as possible.

Within the last 10 years two summaries of the forest situation, national in scope, have involved growth studies. In the management of the national forests a knowledge of second-growth yields is immediately useful in timber working-circle plans, in land exchange, in fire plans, in fire-damage appraisals, in cooperative fire-protection agreements with private landowners, and in other ways. To the

[1] Maintained in cooperation with the University of California.

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State, yield data are of present value in formulating a land-use policy and in organizing fire protection for areas outside the national forests. Private timber owners may make use of yield tables in evaluating cut-over land for sale or exchange, in determining justifiable expenditures for fire protection, or in plans for continuous forest production. Such uses amply justify the attempt to put into convenient published form the data at present available, even though the complexity of yield-table construction for mixed stands and the difficulty in finding a sufficient number of adequate sample plots render these tables wholly tentative and preliminary in character.

THE FOREST TYPES

COMPOSITION

The stands to which the following tables apply are composed of ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*P. lambertiana* Dougl.), Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.), white fir (*Abies concolor* Lindl. and Gord.), and red fir (*A. magnificia* A. Murray). Incense cedar (*Libocedrus decurrens* Torr.), although it also is almost invariably present (rare exceptions being in true fir stands) and frequently numerous, particularly in the younger age classes, rately makes up more than 5 to 10 per cent of the volume of the stand.

The foregoing species appear in the stands in incalculably varying proportions, and yet, within clearly defined limits of altitude, latitude, and aspect, several types may be easily recognized. The types considered in this bulletin are shown in Table 1. The grouping of species into types is based on the arbitrary assumption that a species is a component of the type if it forms 20 per cent or more of the total basal area.

TABLE 1.—*Composition of types, by species, in percentage of total basal area*

Species group or type	Ponderosa pine	Sugar pine	Douglas fir	White fir	Incense cedar	Red fir
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Ponderosa pine-fir	40	3	30	20	7	--------
Ponderosa pine-sugar pine	40	37	3	10	10	--------
Ponderosa pine-sugar pine-fir	40	25	10	20	5	--------
Sugar pine-fir	5	33	20	35	7	--------
White fir-Douglas fir	5	3	45	45	2	--------
White fir-red fit	--------	3	--------	68	--------	29

RANGE AND OCCURRENCE

The types here discussed cover the west slope of the Sierra Nevada and Cascade Mountains from the Kern River at the south to Mount Shasta at the north, and extend along the northern inner coast ranges from the Oregon line to central Lake County. The east-slope sierra and northeast plateau forests, where ponderosa and Jeffrey pines predominate, are not included in the discussion. The redwood and other forests of the northern outer coast ranges are also excluded.

The altitudinal limits of commercial stands vary with latitude and aspect. In the southern sierra good stands are rarely found below 3,000 feet, but in the northern inner coast ranges stands occur at elevations of 1,000 feet or less. The upper limit is about 6,500 feet in the south, and 5,000 feet in the north.

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At lower elevations and on southerly aspects at middle elevations, ponderosa pine occurs in pure stands or predominates in mixtures. Toward the north, particularly in canyon bottoms and on north aspects, Douglas fir is frequently the dominant species at lower elevations. The sugar and ponderosa pine mixtures predominate on south slopes and benches between 4,000 and 5,500 feet. The sugar-pine and fir type is rather closely confined to north and northeast aspects at elevations of 4,500 to 6,000 feet. Above 6,000 feet, true firs usually predominate.

The best stands are found at elevations of 4,500 to 5,500 feet along the middle west slopes of the sierra. Here occurs the most favorable combination of precipitation and seasonal temperatures.

In relatively few sections of this large region are the stands uniform in age. All age classes, however, are rarely present, as they would be in a true selection forest. Stands are usually made up of small even-aged groups, the ages of the groups differing by periods of 10 to 20 years or more. The limited occurrence of extensive even-aged stands renders the construction and application of yield tables difficult.

CONDITIONS OF ESTABLISHMENT OF SECOND GROWTH

The occurrence of even-aged second-growth stands, within the limits fixed by nature, is largely a result of human activities. During the gold rush, beginning in 1849, heavy cuttings were made in the stands accessible to the mines. Frequently burning followed cutting, by accident or by design. The stands were rarely clear-cut at one time over considerable areas, but cutting was repeated, and a source of seed remained for some years. During seasons of heavy precipitation, such as the winter of 1861–62, the establishment of seedlings was good. The majority of the best even-aged second growth dates from the decade 1861–1870. Since most of the mining activity was at lower elevations, the greater portion of this second growth is ponderosa pine and Douglas fir.

During construction of the Southern Pacific Railroad through the Sierra, 1862 to 1865, heavy cutting along the right of way was followed by some excellent stands of second growth, varying in composition from pure ponderosa pine to pure fir.

Following the gold rush, stock raising increased rapidly, and range burning became a common practice. Although these range fires converted vast areas of forest into worthless brush, in many instances where conditions were favorable, patches of even-aged second growth were established.

With improved transportation the manufacture of lumber for the general market became important. The cuttings were light, only the more valuable pines being taken, as a rule. The resulting second growth is irregular in age.

Light cutting continued generally until the advent of heavier logging machinery and wider markets, beginning about 1900. From 1900 to about 1925, cutting on private land became more intensive, logging damage increased, and slash burning was more common. The frequency of fires, the failure of seed crops, and the generally poor climatic conditions have resulted in irregular, scanty reproduction for the most part. On national forest selective cuttings since 1906, the second growth is naturally irregular in age. Since 1925, private cutting has generally been lighter, leaving the firs, cedar, and smaller pines. Reproduction in these areas will not be even-aged.

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Thus the conditions favoring the establishment of larger areas of even-aged second growth have largely ceased to exist. Probably the future tendency will be toward selection rather than even-aged stands. On the private land heavily cut or burned between 1900 and 1925, with better fire protection and more abundant precipitation, considerable even-aged reproduction may be expected.

RELATIVE IMPORTANCE OF VIRGIN AND SECOND-GROWTH FOREST

The areas of various classes of forest land in the region, as shown by the type map being prepared by the California Forest and Range Experiment Station, are given in Table 2. The area of virgin timber constitutes about 41 per cent of the area of all commercial timber in California, including redwood.

TABLE 2.—*Areas of forested, restocking, and deforested lands in the California pine region*

Class of forest land	Area of class within pine region	
	Acres	*Per cent*
Virgin timber	4,663,400	47.8
Second growth	1,015,200	46.3
Restocking	869,100	49.7
Deforested	937,100	44.7

The virgin stands are not even-aged. The second growth includes all types of cut-over areas, and only a small percentage of it is even-aged. Restocking areas include mostly brush fields following early fires when the reproduction tends to be even-aged by groups and stocking is very irregular.

The future of the old-growth forests is, of course, uncertain. The pure ponderosa pine and the ponderosa pine-sugar pine types will doubtless be cut out first because of high value and accessibility. The comparatively small area of sugar pine-fir type will be culled for the sugar pine rather early. Types with a heavier proportion of Douglas fir and true firs will probably not be cut extensively until the available pine types are exhausted. It is to be expected that the privately owned stands will be largely cut over by the end of the century. They are more accessible, better stocked, and have a larger proportion of pines than the public forests.

The treatment of the remaining virgin timber will determine the future of second growth. So long as virgin timber is available, little cutting of second growth is to be expected. No cutting of consequence has occurred in young growth to date. Indications are that the ponderosa pine stands established 60 to 70 years ago will be the first second-growth utilized extensively.

THE DATA

The chief source of the material used in this study was a group of 224 plots measured by Dunning and Show (1912–1923). Permanent sample plots established later by the California Forest Experiment Station and other plots measured by F. X. Schumacher, then of the University of California, were also used. The total number of plots finally selected for the study was 311.

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In several ways these plots were not entirely satisfactory. The outstanding feature is the irregular distribution by age. (Table 4.) The great preponderance of plots between the ages of 50 and 69 years is due, as has been shown, to the cuttings and frequent fires of the gold-mining period. Stands of other age classes are of relatively infrequent occurrence and hard to find.

Then, again, truly normal stands were so rare that, to obtain a sufficient number, a wider range of density of stocking than would ordinarily be permitted was unavoidable. Still further variation in stocking was doubtless due to the great variation in composition, which affected to some extent the judgment used in the selection of plots.

The field technic used when the earlier measurements were made by Dunning and Show differed in some details from the standard technic of the present. Curves of height over diameter were not prepared, and the height used for site classification was the average height of the dominant trees, rather than the height corresponding to the average diameter of the dominant and codominant trees. In addition, some of the plots were rather small, containing less than 100 trees, the present acceptable minimum. Despite these deficiencies, however, the data were of enough value to justify the construction of yield tables.

METHODS USED IN ANALYSIS OF DATA

The types themselves, in the relationship between component species, present a complex problem not encountered in the pure stands that are the basis of most of the recent work on second-growth yield tables. Although Haig's (*5*)[2] yield tables for western white pine in the northern Rocky Mountain region deal with a mixed-species forest, the associated species introduce no great complications since with increasing age they tend to disappear. No such tendency is noted in the California pine types, the component species of any young stand having equal likelihood of predominance at maturity.

This tendency to maintain the original composition throughout life requires, for the correct determination of site quality, an analysis of the interrelationship between species. It also requires an evaluation of the relative influence each species exerts upon such stand measurements as basal area, number of trees, etc. Such an evaluation, complicated by the endless variations in the proportions of the different species, ranging from almost pure stands of each species (except incense cedar) to any combination of two or more species, is complicated further by variations in density of stocking which tend to mask the effects of composition. Obviously, some method of measuring, defining, and compensating for stand density must be employed.

In general, the method of analysis consisted in assigning values for density of stocking to each plot and then modifying the stand measurements to represent the average of well-stocked stands. These modified values were used as a basis for constructing tables for average stocking and composition by the standard technic (*3*, *7*). The percentage deviations of the original individual plot values from this average table were then correlated with density of stocking and

[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

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percentage composition by species. (Based on species distribution of basal area.) The resulting multiple regression equations gave the

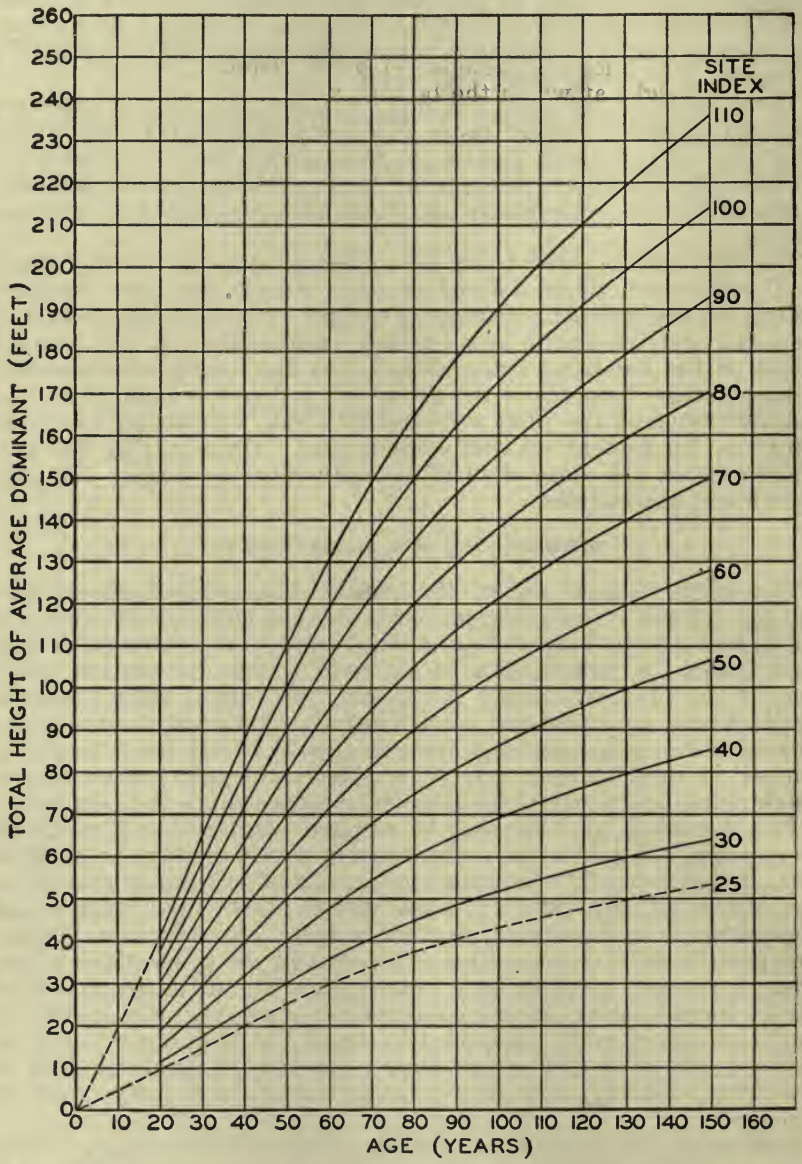

FIGURE 1.—Site-classification curves, based upon the total height of the dominant tree of average basal area, of ponderosa pine, white fir, Douglas fir, and red fir, separately or in combination

appropriate factors to apply to the average table for any conditions of stocking and composition.

A detailed description of those particulars wherein the technic differed from standard procedure is given in the appendix.

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YIELDS

AGE

The ages of the stands sampled were determined by ring counts on borings, usually at breast height, of dominant and codominant trees, corrected for the number of years required for the trees to reach the height at which the borings were made. The average age of the trees bored was taken as the age of the stand; no allowance was made for the period between the removal of the original stand and the establishment of the new stand.

SITE INDEX (OR QUALITY)

The classification of the sample plots according to site quality is based on the relationship between age and the average height of the dominant trees. Ponderosa pine, white fir, red fir, and Douglas fir have essentially the same height-age relationship when growing in mixed stands, and dominant trees of all the species named should be used as they are present.

Figure 1 and Table 3 show this relationship between age and height of dominant trees. The various site qualities are denoted by a site index expressed in height in feet attained at an age of 50 years. Obviously, a complete series of 1-foot site indices could be given but, for convenience, curves and tabular values are given only for even 10-foot intervals, from which intermediate values may be ascertained by interpolation. The determination of site index is simple; the average dominant height is plotted over the age on Figure 1, and the site index taken either from the curve nearest to the plotted point or from an interpolated index curve.

TABLE 3.—*Total height in feet of average dominant tree* [1] *on all sites*

Age (years)	Height on—									
	Site index 25	Site index 30	Site index 40	Site index 50	Site index 60	Site index 70	Site index 80	Site index 90	Site index 100	Site index 110
20	9.4	11.3	15.0	18.8	22.6	26.3	30.1	33.9	37.6	41.4
30	14.6	17.5	23.4	29.2	35.1	40.9	46.8	52.6	58.4	64.3
40	19.9	23.9	31.8	39.8	47.8	55.7	63.7	71.7	79.6	87.6
50	25.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0
60	29.7	35.7	47.6	59.5	71.4	83.3	95.1	107	119	131
70	34.0	40.8	54.3	67.9	81.5	95.1	109	122	136	149
80	37.6	45.1	60.1	75.1	90.1	105	120	135	150	165
90	40.6	48.7	64.9	81.1	97.4	114	130	146	162	178
100	43.2	51.8	69.1	86.4	104	121	138	156	173	190
110	45.6	54.7	72.9	91.1	109	128	146	164	182	201
120	47.7	57.3	76.4	95.5	115	134	153	172	191	210
130	49.8	59.7	79.7	99.6	119	139	159	179	199	219
140	51.7	62.0	82.7	103	124	145	165	186	207	228
150	53.5	64.2	85.6	107	128	150	171	193	214	236

[1] Based on dominant ponderosa pine, Douglas fir, red fir, and white fir; all four species to be used when present in the stand.

Table 4 shows how the 311 sample plots used are distributed as to age and site quality, and illustrates the preponderance of plots in the 50–59 year and 60–69 year age classes.

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TABLE 4.—*Distribution of plots by age and site index*

Age (years)	Number of plots on—									
	Site indices 25–29	Site indices 30–39	Site indices 40–49	Site indices 50–59	Site indices 60–69	Site indices 70–79	Site indices 80–89	Site indices 90–99	Site indices 100–109	All sites
40 to 49				2	7	5	4	1		19
50 to 59	1	1	8	27	54	34	19	13	6	163
60 to 69		1	10	25	26	17	4	4		87
70 to 79			1		3	3	3			10
80 to 89			1		3					4
90 to 99		1		1	5	1	3			11
100 to 109					2				1	3
110 to 119				1	2	2	3			8
120 to 129					1	1				2
130 to 139						1				1
140 to 149				1		2				3
All ages	1	3	20	57	103	66	36	18	7	311

DENSITY OF STOCKING AND STAND-DENSITY INDEX

The criterion adopted for evaluating the density of the stand, or stocking, is the relationship between the number of trees per acre and their average diameter, shown by the solid line of Figure 2. This is a reference curve used for determining a stand-density index.[3] The series of broken-line curves parallel to the reference curve serve a similar purpose to the curves in Figure 1 in supplying a ready means of estimating stand-density index. The number of trees per acre shown by each curve at an average diameter of 10 inches is the stand-density index of that curve. For a given stand, the line lying nearest the point defined by number of trees per acre plotted over average diameter can be read as the stand-density index. For example, the plotted point representing a stand with 350 trees per acre and an average diameter by basal area of 15 inches will fall nearest the curve representing a stand-density index of 700. By interpolating between the curves, a more precise index of 670 may be obtained.

The stand-density indices of the sample plots of this study ranged from 230 to 850, with an average value of 479. Taking 800 as a fair index for full stocking in these mixed-conifer stands, the average stand-density index of 479 represents approximately 60 per cent of full stocking. Individual plots ranged from 29 to 106 per cent. The distribution of the plots by stand-density index is given below:

Stand-density index:	Number of plots
200 to 299	6
300 to 399	49
400 to 499	102
500 to 599	80
600 to 699	50
700 to 799	18
800 to 899	6
Total	311

TOTAL BASAL AREA

Total basal area, or the sum of the breast-high cross-section areas of all trees 2 inches and larger in diameter is shown in Table 5 and Figure 3 for the average of well-stocked stands and average composi-

[3] REINEKE, L. H. PERFECTING A STAND-DENSITY INDEX FOR EVEN-AGED STANDS. (Unpublished manuscript.)

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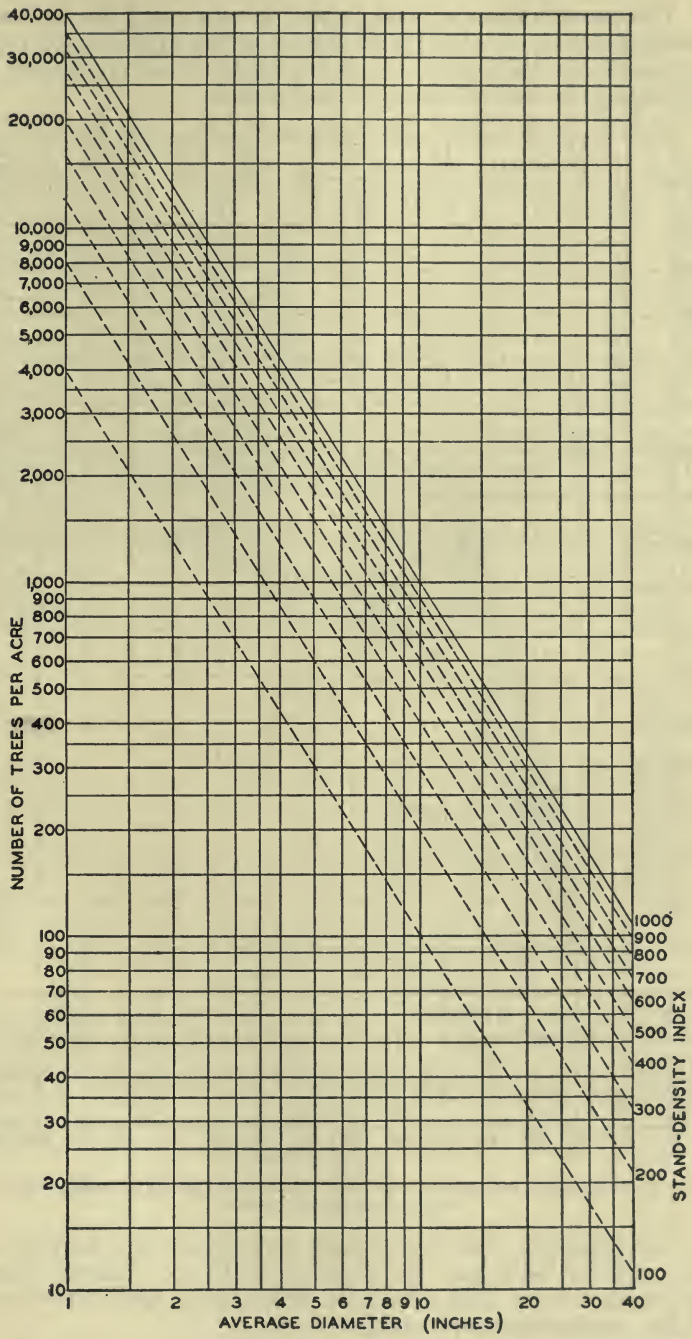

FIGURE 2.—Stand-density index curves. When, for a given stand, trees per acre over average diameter by basal area is plotted, the stand-density index is determined in round numbers by the nearest curve, or more exactly by interpolation

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tion. The modification of this table for any condition of stocking and composition is effected by substituting the appropriate values in the regression equation given under the table and applying the resulting percentage to the values given in Table 5.

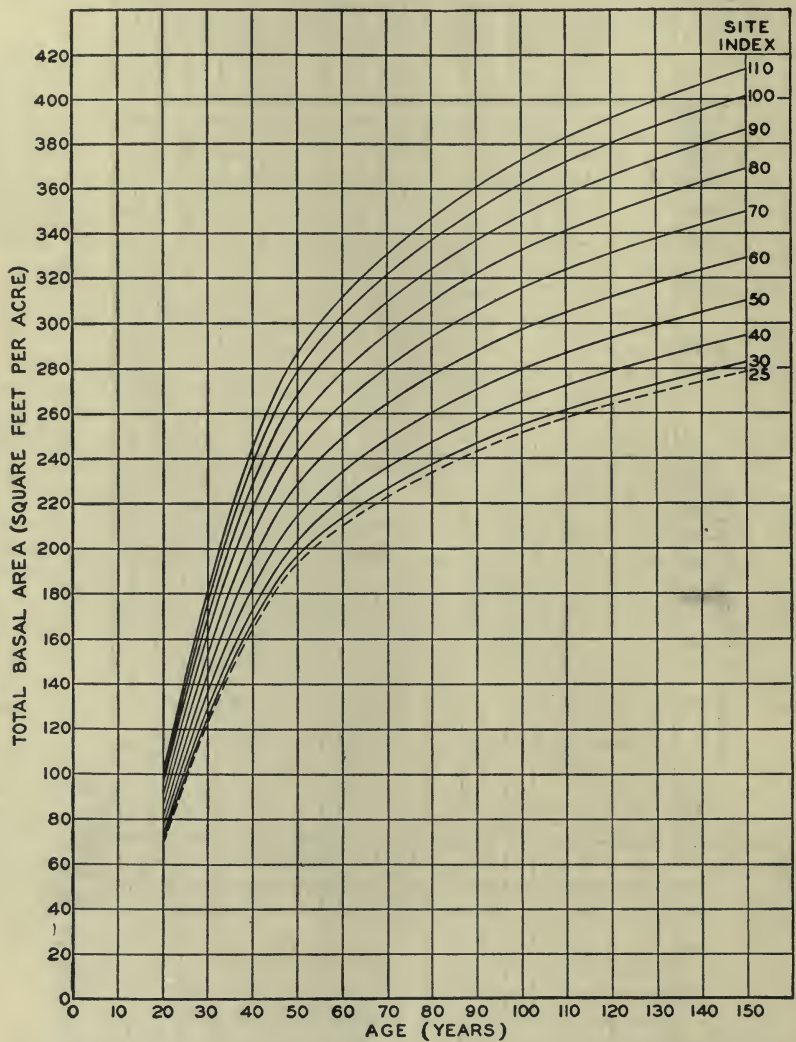

FIGURE 3.—Relationship between age, site index, and total basal area for average well-stocked stands of average composition

For convenience, the percentage corrections for various stand-density indices, by types, are given in Table 6. Minor differences in composition from that given for these types will not change the correction percentage appreciably.

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TABLE 5.—*Total basal area, average stands* [1]

Age (years)	Basal area (square feet per acre) by site-index classes									
	Site 25	Site 30	Site 40	Site 50	Site 60	Site 70	Site 80	Site 90	Site 100	Site 110
30	124	126	131	138	146	155	164	172	178	184
40	165	168	175	184	196	208	219	229	238	245
50	194	197	205	216	230	244	257	269	280	288
60	210	213	222	234	248	264	278	291	303	311
70	223	226	236	248	264	280	295	309	321	331
80	234	237	247	260	277	294	310	324	337	347
90	243	247	257	271	288	305	322	337	350	361
100	252	255	266	280	298	316	333	349	363	373
110	258	262	273	287	305	324	342	358	372	383
120	264	268	279	294	312	332	350	366	381	392
130	269	273	285	300	319	338	357	374	388	400
140	274	278	290	305	324	344	363	380	395	407
150	278	282	294	310	329	350	369	386	401	413

[1] For specific stands, substitute in the following equation and apply resulting percentage to the tabular values: Total basal area (in percentage of composite table) = 2.0303 (percentage stocking) + 0.1493 (ponderosa pine per cent) + 0.1545 (sugar pine per cent) + 0.0541 (Douglas fir per cent) + 0.0980 (white fir per cent) + 0.1229 (incense cedar per cent) + 0.1883 (red fir per cent) − 8.1511.

TABLE 6.—*Percentage correction of values in Table 5 for different types* [1]

Stand-density index	Ponderosa pine–fir	Ponderosa pine–sugar pine	Ponderosa pine–sugar pine–fir	Sugar pine–fir	White fir–Douglas fir	White fir–red fir
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	43.33	46.51	45.40	43.67	40.76	37.92
250	53.49	56.67	55.56	53.82	50.91	48.07
300	63.64	66.82	65.71	63.98	61.06	58.22
350	73.79	76.97	75.86	74.13	71.21	68.37
400	83.94	87.12	86.01	84.28	81.36	78.52
450	94.09	97.27	96.16	94.43	91.51	88.67
500	104.24	107.42	106.31	104.58	101.66	98.82
550	114.39	117.58	116.47	114.73	111.82	108.98
600	124.55	127.73	126.62	124.88	121.97	119.13
650	134.70	137.88	136.77	135.04	132.12	129.28
700	144.85	148.03	146.92	145.19	142.27	139.43
750	155.00	158.18	157.07	155.34	152.42	149.58
800	165.15	168.33	167.22	165.49	162.57	159.73

[1] Aggregate deviation, less than 0.5 per cent; average percentage deviation, 5.22 per cent.

NUMBER OF TREES PER ACRE

The number per acre of all trees 2 inches or more in breast-high diameter is given in Table 7 and Figure 4 for average stocking and composition. Modification for specific stocking and composition is made as for total basal area. Table 8 gives the percentages for the six types.

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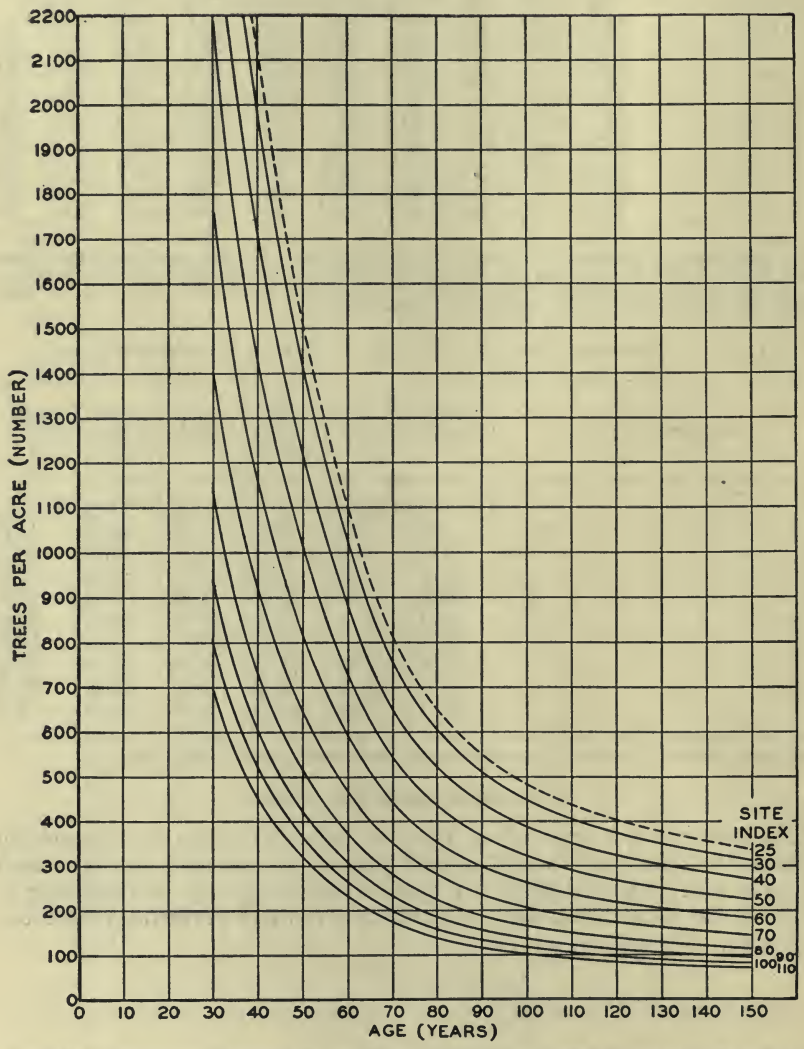

FIGURE 4.—Relationship between age, site index, and number of trees per acre for average well-stocked stands of average composition

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TABLE 7.—*Number of trees, average stands* [1]

Age (years)	Number of trees per acre, by site index class									
	Site 25	Site 30	Site 40	Site 50	Site 60	Site 70	Site 80	Site 90	Site 100	Site 110
30	3,260	3,030	2,620	2,175	1,770	1,400	1,120	922	790	690
40	2,110	1,960	1,695	1,405	1,145	906	723	596	511	446
50	1,500	1,395	1,205	1,000	814	645	515	424	364	318
60	1,095	1,020	879	730	594	470	375	309	265	232
70	807	750	648	538	438	347	277	228	196	171
80	648	602	520	432	351	278	222	183	157	137
90	547	509	439	365	297	235	188	155	133	116
100	481	447	386	321	261	207	165	136	117	102
110	437	406	351	291	237	188	150	123	106	92
120	403	374	323	268	218	173	138	114	98	85
130	377	350	303	251	204	162	129	107	91	80
140	356	331	286	237	193	153	122	101	86	75
150	337	313	270	224	182	145	115	95	82	71

[1] For specific stands, substitute in the following equation and apply resulting percentage to the tabular values: Number of trees (in percentage of composite table) = 2.0058 (percentage of stocking) − 0.3166 (ponderosa pine per cent) − 0.2973 (sugar pine per cent) − 0.0159 (Douglas fir per cent) − 0.1355 (white fir per cent) − 0.1358 (incense cedar per cent) − 0.0905 (red fir per cent) + 19.3572.

TABLE 8.—*Percentage correction of values in Table 7 for different types* [1]

Stand-density index	Ponderosa pine–fir	Ponderosa pine–sugar pine	Ponderosa pine–sugar pine–fir	Sugar pine–fir	White fir–Douglas fir	White fir–red fir
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	41.78	33.05	35.83	42.07	49.91	46.74
250	51.81	43.08	45.86	52.10	59.94	56.77
300	61.84	53.11	55.89	62.13	69.97	66.80
350	71.87	63.14	65.92	72.16	80.00	76.83
400	81.90	73.16	75.94	82.18	90.03	86.86
450	91.92	83.19	85.97	92.21	100.06	96.89
500	101.95	93.22	96.00	102.24	110.09	106.92
550	111.98	103.25	106.03	112.27	120.12	116.95
600	122.01	113.28	116.06	122.30	130.15	126.97
650	132.04	123.31	126.09	132.33	140.17	137.00
700	142.07	133.34	136.12	142.36	150.20	147.03
750	152.10	143.37	146.15	152.39	160.23	157.06
800	162.13	153.40	156.18	162.42	170.26	167.09

[1] Aggregate deviation, less than 0.5 per cent; average percentage deviation, 18.4 per cent.

AVERAGE DIAMETER OF THE STAND

The average breast-high diameter of the stand is the diameter of the tree of average basal area as determined by dividing total basal area by number of trees. Table 9 and Figure 5 give these values for stands of average stocking and composition. For stands of other than average stocking or composition, average breast-high diameter should be derived by dividing the corrected total basal area by the corrected number of trees and converting the resultant average basal area into its equivalent diameter.

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TABLE 9.—*Average breast-high diameter in inches of average stands, by site-index classes*

Age (years)	Site 25	Site 30	Site 40	Site 50	Site 60	Site 70	Site 80	Site 90	Site 100	Site 110
30	2.64	2.76	3.03	3.41	3.89	4.51	5.18	5.85	6.43	6.99
40	3.79	3.96	4.35	4.90	5.60	6.49	7.45	8.39	9.24	10.0
50	4.87	5.09	5.59	6.29	7.20	8.33	9.56	10.8	11.9	12.9
60	5.93	6.19	6.81	7.67	8.75	10.1	11.7	13.1	14.5	15.7
70	7.12	7.43	8.17	9.19	10.5	12.2	14.0	15.8	17.3	18.8
80	8.14	8.50	9.33	10.5	12.0	13.9	16.0	18.0	19.8	21.5
90	9.02	9.43	10.4	11.7	13.3	15.4	17.7	20.0	22.0	23.9
100	9.80	10.2	11.2	12.6	14.5	16.7	19.2	21.7	23.9	25.9
110	10.4	10.9	11.9	13.5	15.4	17.8	20.4	23.1	25.4	27.6
120	11.0	11.5	12.6	14.2	16.2	18.8	21.6	24.3	26.7	29.0
130	11.4	12.0	13.1	14.8	16.9	19.6	22.5	25.3	28.0	30.3
140	11.9	12.4	13.6	15.4	17.5	20.3	23.4	26.3	29.0	31.5
150	12.3	12.9	14.2	15.9	18.2	21.0	24.3	27.3	29.9	32.7

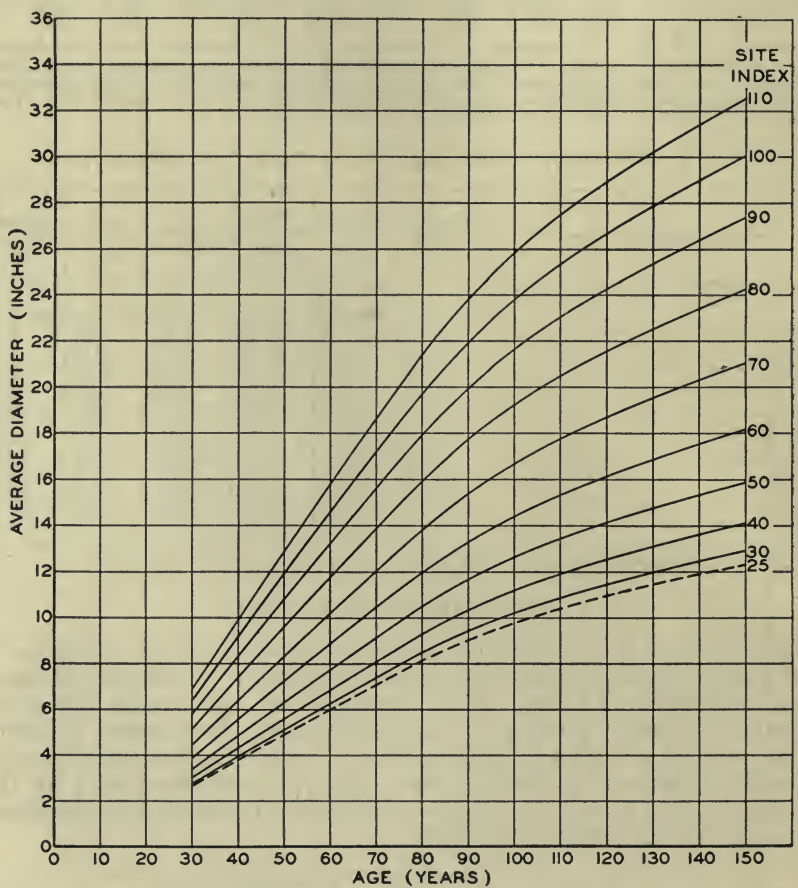

FIGURE 5.—Relationship between age, site index, and average diameter per acre, for average well-stocked stands of average composition

VOLUME PER ACRE IN CUBIC FEET

Table 10 and Figure 6 show for stands of average stocking and composition the total cubic-foot volume inside bark, including stump and top, of all trees 2 inches and larger in diameter. Correction percentages are given in Table 11 for the six types.

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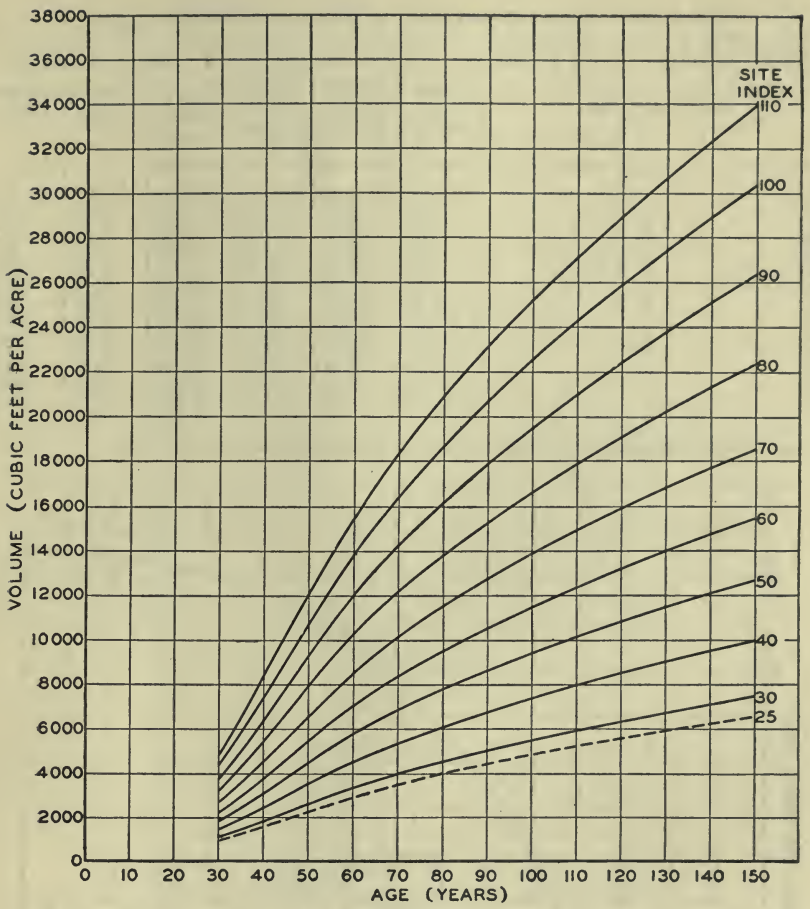

FIGURE 6.—The volumes in cubic feet (inside bark, stump and top included, for average well-stocked stands of average composition

TABLE 10.—*Volume per acre in cubic feet, average stands* [1]

Age (years)	Volume in cubic feet per acre on site index—									
	25	30	40	50	60	70	80	90	100	110
30	930	1,060	1,420	1,800	2,200	2,650	3,200	3,770	4,380	4,850
40	1,590	1,800	2,410	3,090	3,770	4,550	5,500	6,500	7,450	8,450
50	2,260	2,590	3,480	4,440	5,420	6,560	7,940	9,300	10,700	12,000
60	2,950	3,350	4,510	5,790	7,020	8,550	10,300	12,100	13,900	15,500
70	3,500	4,000	5,350	6,850	8,450	10,200	12,200	14,300	16,500	18,400
80	4,000	4,540	6,100	7,800	9,520	11,500	13,800	16,200	18,600	20,900
90	4,420	5,000	6,750	8,600	10,500	12,700	15,200	17,800	20,700	23,100
100	4,830	5,500	7,400	9,450	11,500	13,900	16,600	19,500	22,600	25,200
110	5,200	5,950	8,000	10,200	12,300	14,900	17,900	21,000	24,250	27,200
120	5,600	6,390	8,550	10,800	13,200	16,000	19,100	22,500	26,000	29,000
130	5,900	6,700	9,050	11,500	14,000	16,900	20,300	24,000	27,500	30,700
140	6,220	7,070	9,550	12,100	14,750	17,750	21,400	25,200	29,000	32,400
150	6,550	7,430	10,000	12,700	15,450	18,550	22,400	26,400	30,400	34,000

[1] For specific stands, substitute in the following equation and apply resulting percentage to the tabular values: Volume in cubic feet (in percentage of composite table)=1.5251 (percentage of stocking)−0.7170 (ponderosa pine per cent)−0.7740 (sugar pine per cent)−0.9398 (Douglas fir per cent)−1.0704 (white fir per cent)−0.8427 (incense cedar per cent)−1.1996 (red fir per cent)+128.7553.

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TABLE 11.—*Percentage correction of Table 10 for different types* [1]

Stand density index	Ponderosa pine–fir	Ponderosa pine–sugar pine	Ponderosa pine–sugar pine–fir	Sugar pine–fir	White fir–Douglas fir	White fir–red fir
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
200	74.01	79.99	76.21	67.97	61.21	49.36
250	81.64	87.61	83.83	75.60	68.83	56.99
300	89.27	95.24	91.46	83.22	76.46	64.61
350	96.89	102.87	99.08	90.85	84.08	72.24
400	104.52	110.49	106.71	98.47	91.71	79.86
450	112.14	118.12	114.34	106.10	99.33	87.49
500	119.77	125.74	121.96	113.72	106.96	95.11
550	127.39	133.37	129.59	121.35	114.58	102.74
600	135.02	140.99	137.21	128.98	122.21	110.36
650	142.64	148.62	144.84	136.60	129.84	117.99
700	150.27	156.24	152.46	144.23	137.46	125.61
750	157.89	163.87	160.09	151.85	145.09	133.24
800	165.52	171.49	167.71	159.48	152.71	140.87

[1] Aggregate deviation, less than 0.5 per cent; average percentage deviation, 16.4 per cent.

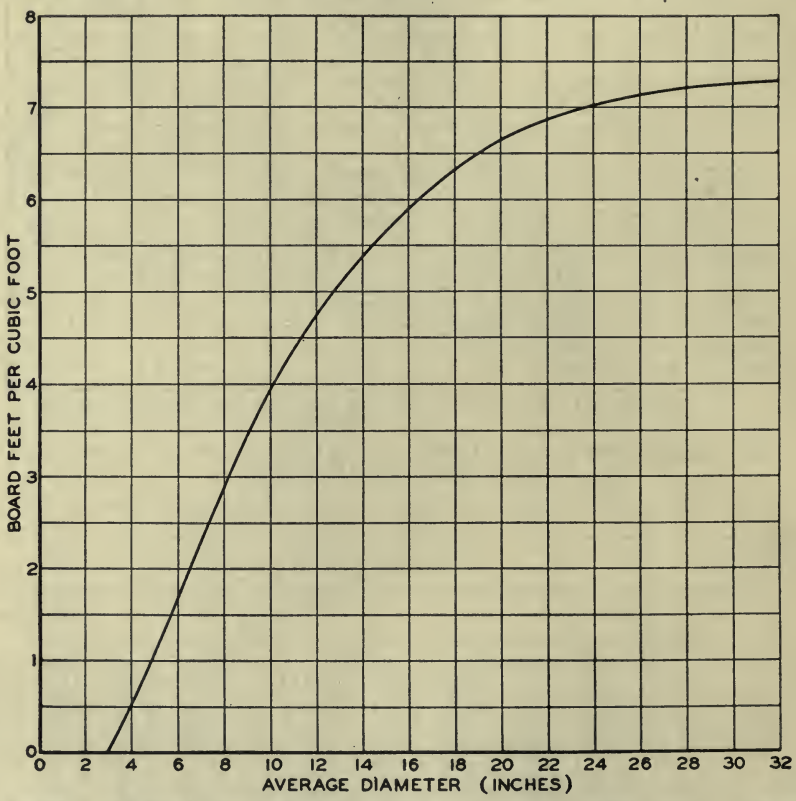

FIGURE 7.—The ratio of volume of stand in board feet to volume in cubic feet, in relation to average diameter of stand

RATIO OF BOARD FEET TO CUBIC FEET

The ratio of board feet to cubic feet is closely correlated with average diameter and is independent of age and site quality. In the standard yield-table technic, this relationship is applied to the table

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of volume in cubic feet to obtain the table of volume in board feet. Table 12 and Figure 7 give the board foot-cubic foot ratios used. The values given are ratios of volume in board feet of trees 8 inches and larger to the volume in cubic feet of all trees 2 inches and larger.

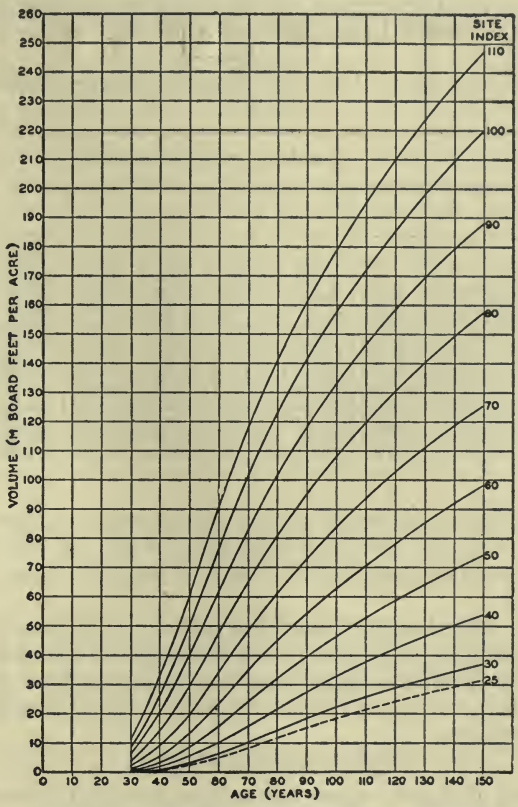

FIGURE 8.—Volume in board feet by the international rule (⅛-inch kerf), trees 8 inches and larger, average of well-stocked stands, average composition.

TABLE 12.—*Board-foot conversion table*

Age (years)	Board feet per cubic foot by site-index classes									
	Site 25	Site 30	Site 40	Site 50	Site 60	Site 70	Site 80	Site 90	Site 100	Site 110
30	-------	-------	0.06	0.25	0.50	0.80	1.20	1.60	1.98	2.29
40	0.44	0.52	.72	1.04	1.47	2.00	2.60	3.15	3.60	3.96
50	1.02	1.15	1.45	1.87	2.44	3.10	3.76	4.31	4.72	5.06
60	1.60	1.82	2.21	2.72	3.35	4.01	4.65	5.12	5.52	5.82
70	2.38	2.56	2.98	3.55	4.19	4.80	5.36	5.82	6.19	6.46
80	2.98	3.20	3.60	4.19	4.76	5.36	5.90	6.32	6.60	6.81
90	3.50	3.70	4.14	4.65	5.17	5.75	6.30	6.65	6.87	7.01
100	3.85	4.05	4.47	4.96	5.49	6.06	6.52	6.84	7.00	7.12
110	4.14	4.35	4.76	5.24	5.75	6.30	6.71	6.96	7.10	7.19
120	4.39	4.58	4.96	5.44	5.94	6.46	6.83	7.04	7.16	7.23
130	4.58	4.76	5.12	5.60	6.11	6.59	6.92	7.10	7.20	7.26
140	4.72	4.90	5.26	5.75	6.24	6.68	6.98	7.15	7.23	7.27
150	4.87	5.06	5.44	5.87	6.36	6.78	7.04	7.18	7.25	7.29

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VOLUME PER ACRE IN BOARD FEET

Volumes in board feet of all trees 8 inches and larger in diameter, for stands of average stocking and composition, are given in Table 13 and Figure 8. The log rule used is the International, ⅛-inch kerf, and the volume is of that part of the stem between a stump 1 foot high and a top diameter inside bark of 5 inches.

TABLE 13.—*Volume per acre in board feet (International rule, ⅛-inch kerf), average stands*

Age (years)	Board feet per acre on site index—									
	25	30	40	50	60	70	80	90	100	110
30	-------	-------	85	450	1,100	2,120	3,840	6,030	8,670	11,110
40	700	940	1,740	3,210	5,540	9,100	14,300	20,500	26,800	33,450
50	2,300	2,980	5,050	8,300	13,200	20,340	29,850	40,100	50,500	60,700
60	4,720	6,100	9,970	15,750	23,500	34,300	47,900	61,950	76,750	90,200
70	8,330	10,250	15,950	24,300	35,400	48,950	65,400	83,250	102,100	118,900
80	11,900	14,550	21,950	32,700	45,300	61,650	81,400	102,400	122,800	142,300
90	15,450	18,500	27,950	40,000	54,300	73,000	95,750	118,400	142,200	161,900
100	18,600	22,300	33,100	46,850	63,150	84,250	108,200	133,400	158,200	179,400
110	21,550	25,900	38,100	53,450	70,700	93,850	120,100	146,200	172,200	195,600
120	24,600	29,250	42,400	58,750	78,400	103,400	130,500	158,400	186,200	209,700
130	27,000	31,900	46,350	64,400	85,550	111,400	140,500	170,400	198,000	222,900
140	29,350	34,650	50,250	69,600	92,050	118,600	149,400	180,200	209,700	235,500
150	31,900	37,600	54,400	74,550	98,250	125,800	157,700	189,600	220,400	247,900

This table was constructed in the usual manner, by multiplying cubic-foot volume for any age and site index by the board foot-cubic foot ratio corresponding to the average diameter for that age and site index.

This average table is corrected for specific stocking and composition in a similar manner. The corrected average diameter is first determined, and the corresponding board foot-cubic foot ratio is then multiplied by the corrected volume in cubic feet, giving the corrected volume in board feet.

MEAN ANNUAL INCREMENT

Table 14 and Figure 9 show the mean annual increment in cubic feet, for stands of average stocking and composition. These values were derived by dividing the values in Table 10 by the corresponding ages. Mean annual increment culminates at 70 years for any site quality.

TABLE 14.—*Mean annual growth in cubic feet per acre, average stands*

Age (years)	Mean annual growth in cubic feet per acre on site index—									
	25	30	40	50	60	70	80	90	100	110
30	31.00	35.33	47.33	60.00	73.33	88.33	106.67	125.67	146.00	161.67
40	39.75	45.00	60.25	77.25	94.25	113.75	137.50	162.50	186.25	211.25
50	45.20	51.80	69.60	88.80	108.40	131.20	158.80	186.00	214.00	240.00
60	49.17	55.83	75.17	96.50	117.00	142.50	171.67	201.67	231.67	258.33
70	50.00	57.14	76.43	97.86	120.71	145.71	174.29	204.29	235.71	262.86
80	50.00	56.75	76.25	97.50	119.00	143.75	172.50	202.50	232.50	261.25
90	49.11	55.56	75.00	95.56	116.67	141.11	168.89	197.78	230.00	256.67
100	48.30	55.00	74.00	94.50	115.00	139.00	166.00	195.00	226.00	252.00
110	47.27	54.09	72.73	92.73	111.82	135.45	162.73	190.91	220.45	247.27
120	46.67	53.25	71.25	90.00	110.00	133.33	159.17	187.50	216.67	241.67
130	45.38	51.54	69.62	88.46	107.69	130.00	156.15	184.62	211.54	236.15
140	44.43	50.50	68.21	86.43	105.36	126.79	152.86	180.00	207.14	231.43
150	43.67	49.53	66.67	84.67	103.00	123.67	149.33	176.00	202.67	226.67

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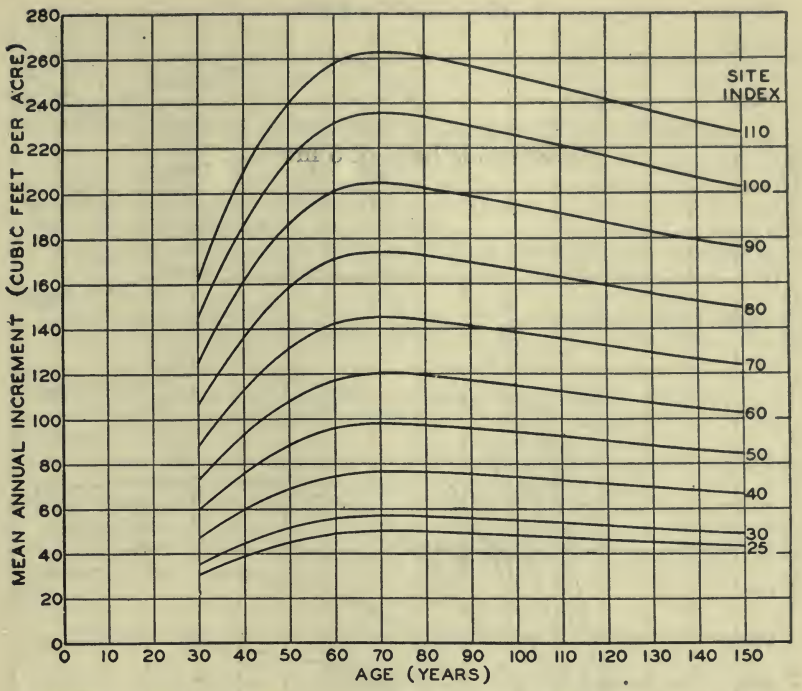

FIGURE 9.—Mean annual increment in cubic-foot volume culminates at 70 years on all sites

Table 15 and Figure 10 show the mean annual increment in board feet. The age of culmination varies with site quality, from 95 years for site index 110 to over 150 years for site index 30. For site index 70 the age of culmination is about 120 years.

TABLE 15.—*Mean annual growth in board feet per acre (international rule, ⅛-inch kerf), average stands*

Age (years)	Mean annual growth in board feet per acre on site index—									
	25	30	40	50	60	70	80	90	100	110
30			2.8	15.0	36.7	70.7	128.0	201.0	289.0	370.3
40	17.5	23.5	43.5	80.2	138.5	227.5	357.5	512.5	670.0	836.2
50	46.0	59.6	101.0	166.0	264.0	406.8	597.0	802.0	1,010.0	1,214.0
60	78.7	101.7	166.2	262.5	391.7	571.7	798.3	1,032.5	1,279.2	1,503.3
70	119.0	146.4	227.9	347.1	505.7	699.3	934.3	1,189.3	1,458.6	1,698.6
80	148.8	181.9	274.4	408.8	566.2	770.6	1,017.5	1,280.0	1,535.0	1,768.8
90	171.7	205.6	310.6	444.4	603.3	811.1	1,063.9	1,315.6	1,580.0	1,778.5
100	186.0	223.0	331.0	468.5	631.5	842.5	1,082.0	1,334.0	1,582.0	1,794.0
110	195.9	235.5	346.4	485.9	642.7	853.2	1,091.3	1,329.1	1,565.5	1,778.2
120	205.0	243.8	353.3	489.6	653.3	861.7	1,087.5	1,320.0	1,551.7	1,747.5
130	207.7	245.4	356.5	495.4	658.1	856.9	1,080.8	1,310.8	1,523.1	1,714.6
140	209.6	247.5	358.9	497.1	657.5	847.1	1,067.1	1,287.1	1,497.9	1,682.1
150	212.7	250.7	362.7	497.0	655.0	838.7	1,051.3	1,264.0	1,469.3	1,652.7

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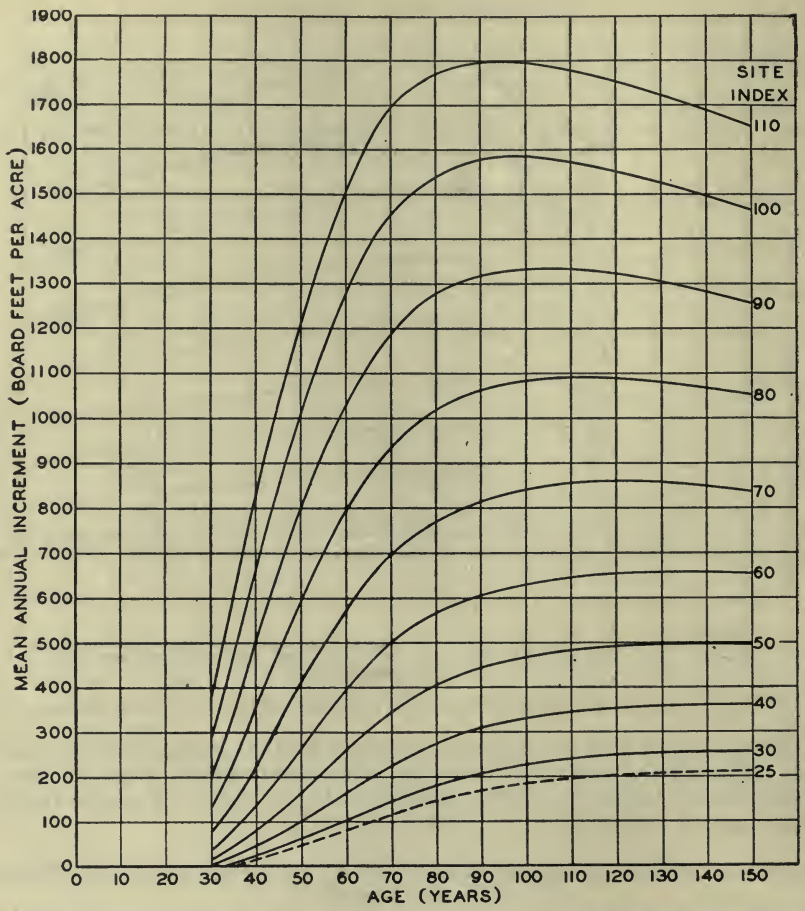

FIGURE 10.—Mean annual increment in board feet culminates at 95 years on the best sites and at 150 years and more on the poorest sites

SUMMARY

With the continued depletion of old-growth stands in the very important mixed conifer type of California there is increasing need for adequate tables of the second-growth timber that is rapidly coming in on many cut-over areas in this region. The tables here presented are based in the main on intensive studies of 311 sample plots which were selected as supplying reasonably representative, although inevitably incomplete data. The position, range, and occurrence of the second-growth mixed conifer stands is described as well as the conditions for their establishment and the relative importance of virgin and second-growth forest in this type.

In view of the number of unusual features that were involved in this yield study a careful explanation of the technic employed in the preparation of the tables is included as an appendix.

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LITERATURE CITED

(1) Baker, F. S.
1923. NOTES ON THE COMPOSITION OF EVEN-AGED STANDS. Jour. Forestry 21: 712–717, illus.

(2) Bruce, D.
1923. PRELIMINARY YIELD TABLES FOR SECOND-GROWTH REDWOOD. Calif. Agr. Expt. Sta. Bul. 361, p. 425–467, illus.

(3) ———
1926. A METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 32: 543–557, illus.

(4) Bruce D. and Reineke, L. H.
1929. THE USE OF ALINEMENT CHARTS IN CONSTRUCTING FOREST STAND TABLES. Jour. Agr. Research 38: 289–308, illus.

(5) Haig, I. T.
1932. SECOND-GROWTH YIELD, STAND, AND VOLUME TABLES FOR THE WESTERN WHITE PINE TYPE. U. D. Dept. Agr. Tech. Bul. 323, 68 p., illus.

(6) Meyer, W. H.
1930. DIAMETER DISTRIBUTION SERIES IN EVEN-AGED FOREST STANDS. Yale Univ. School Forestry Bul. 28, 105 p., illus.

(7) Reineke, L. H.
1927. A MODIFICATION OF BRUCE'S METHOD OF PREPARING TIMBER-YIELD TABLES. Jour. Agr. Research 35: 843–856, illus.

(8) Schumacher, F. X.
1926. YIELD, STAND, AND VOLUME TABLES FOR WHITE FIR IN THE CALIFORNIA PINE REGION. Calif. Agr. Expt. Sta. Bul. 407, 26 p., illus.

APPENDIX

SPECIAL TECHNIC USED IN THE PREPARATION OF THE TABLES

SITE INDEX

The mixed-conifer types present a problem in the determination of site quality by reason of their variation in composition. If dominant trees of a given species were invariably present, the height of trees of that species alone could be used as the index of site quality. Since this is not the case, the relative height growths of the various species must be compared, to determine which species it is desirable to use and to what extent the heights of each depart from the heights of the other species.

The actual analysis showed a simple solution for the problem. The height of the average dominant tree of each species on a plot was first determined. Using all plots for which such values could be determined for two or more species, it was found that white fir was common to nearly all. Accordingly, dominant heights of other species on each plot were expressed as a percentage of the dominant height of white fir. The percentages so derived were then plotted over age, by species. The resultant curves were horizontal straight lines and passed through 98 per cent for ponderosa pine and Douglas fir, 100 per cent for red fir, and 90 per cent for sugar pine. (No data were available for incense cedar, rarely dominant.) This is in close agreement with the values obtained by Schumacher (*8*) and by Bruce (*2*).

These results indicate that site index can be determined directly from white fir, ponderosa pine, Douglas fir, and red fir, alone or in any combination. Naturally, the use of as many of these species as are present will give a more accurate value of site index.

STAND-DENSITY INDEX

In any even-aged stand, the curve of number of trees by breast-high diameter classes has a definite characteristic form, often approaching that of the normal frequency curve (*1*, *4*, *6*). Such a curve can be mathematically described in several ways, a description commonly used being the statement of the mean or average diameter and the standard deviation (*3*). For even-aged stands, however, the numerical value of the standard deviation is positively correlated with the average diameter. Therefore, average diameter alone may be used to describe stands of similar frequency-curve form where extreme accuracy is not needed.

If, then, a large number of stands of the same description, that is, of the same average diameter, be compared as to number of trees per acre, it is obvious that the stand with most trees is the most fully stocked. If this be taken to represent

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the maximum or complete stocking, the number of trees in each of these stands expressed as a percentage of this maximum will give the percentage stocking of the stand.

The number of trees per acre for complete stocking varies with the average diameter of the stand. The curve representing the relationship between number of trees per acre and average diameter corresponds (*8*) to the formula

$$\log \text{number of trees} = -1.605 \log \text{average diameter breast high} + k$$

where k is a constant varying with species. This formula plots as a straight line on logarithmic graph paper (the solid line of Figure 2).

Since the constant k differs with species, it would be impractical to determine its value for the innumerable mixtures of the mixed-conifer types, nor would differences for the common proportions of those species be sufficiently great to justify the attempt. For simplicity then, k was taken as 4.605 to give a curve passing through 1,000 trees per acre at 10 inches average diameter. This curve is used as a reference curve; its elevation is of no importance aside from the convenience of its round-number coordinates (10, 1,000).

The reference curve, thus arbitrarily chosen, is somewhat high for the mixed-conifer stands of this study, though it is not too high for stands of certain other species. It was deemed more desirable, however, to refer stocking to a standard curve suitable for many species than to a curve applicable only to the species of this study. Since this reference curve is higher than the curve representing maximum stocking for the mixed-conifer types, percentage stocking values based on it will be higher than the true percentage stocking. Although this distortion could be easily cared for in any computations involved, it would be somewhat confusing in making mental comparisons. For this reason, the stand-density index was devised.

Any curve representing a constant percentage of the reference curve will plot as a straight line parallel to the reference curve. The curves corresponding to all possible percentages thus constitute an infinite series of parallel curves. Since their slopes are identical, the position of any curve of the series may be defined by any one ordinate and abscissa. If the same abscissa be used for all curves, each curve may be defined by ordinate alone. Accordingly, an abscissa of 10 inches average diameter was chosen, and the ordinate (number of trees per acre) corresponding to this abscissa is termed "stand-density index."

Stand-density index, as here conceived, is obviously independent of species variation in elevation of the curve of maximum number of trees, since it is an absolute, not a relative measure.

The effect of age and site quality on the relationship between number of trees and average diameter is very small. Multiple correlation coefficients for various species ranged from 0.141 ± 0.050 to 0.251 ± 0.049. These are not significant. The corresponding alienation coefficients were 0.990 and 0.968, respectively. For all practical purposes, therefore, no correction need be made for age or site quality.

ADJUSTMENT OF PLOT VALUES FOR STOCKING IN CONSTRUCTION OF TABLES FOR AVERAGE STOCKING

Having a measure of stocking, it should be possible to eliminate the effects of variation in stocking by converting individual plot values to a uniform-stocking basis, thus reducing the dispersion of the plotted points and eliminating the effect of any irregular distribution of stocking. As a result the required curves of the various stand measures for average stocking and composition should be well defined and easily fitted.

The individual plot values for total basal area, number of trees, and cubic-foot volume were accordingly modified by straight proportion between plot stand-density index and average stand-density index (479). Thus, the values for a plot of stand-density index 700 were reduced by the proportion of 700 to 479, and a plot of stand-density index 450 increased by the proportion 450 to 479. The usual pairs of average curves (*7*) such as total basal area over age and percentage of average total basal area over site index, were fitted to the modified values. As expected, the dispersion of the values thus derived was reduced materially, and the trends of the curves were more consistent and better defined.

Since modification for stocking was effected by increasing or decreasing the number of trees of a given average diameter, the average diameter values of the individual plots were not changed. The average curves were based on these original plot values of diameter and checked through the modified total basal area and modified number of tree curves; the agreement between them was very close.

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The board-foot tables are derived from the cubic-foot tables and the curve of board foot–cubic foot ratio; board-foot values, therefore, were not modified for stocking.

ANALYSIS OF EFFECT OF COMPOSITION AND STOCKING

By using the table of total basal area for stands of average stocking and composition, the tabular value corresponding to the age and site index of each sample plot was determined. The basal area of each plot was then expressed as a percentage of this tabular value. These percentages were used as the dependent-variable values in a multiple linear correlation, with percentage stocking and composition by species as the independent variables. The resulting multiple-regression equation was—

Total basal area per cent

=2.0303 (stand-density index) +0.1493 (ponderosa pine per cent) +0.1545 (sugar pine per cent) +0.0541 (Douglas fir per cent) +0.0980 (white fir per cent) +0.1229 (incense cedar per cent) +0.1883 (red fir per cent) −8.1511.

The regression coefficients, in combination with the numerical values of the variables, indicate that variations in stocking account for the greatest part of the variation in basal area, the effect of composition being relatively small.

A similar correlation was made for number of trees per acre, resulting in the regression equation—

Number of trees per cent

=2.0058 (stand-density index) −0.3166 (ponderosa pine per cent) −0.2973 (sugar pine per cent) −0.0159 (Douglas fir per cent) −0.1355 (white fir per cent) −0.1358 (incense cedar per cent) −0.0905 (red fir per cent) +19.3572.

Here, also, the greatest effect is assignable to variation in stand density.

A third correlation was made, in a similar manner, for volume in cubic feet. The resulting regression equation was—

Cubic-foot volume per cent

=1.5251 (stand-density index) −0.7170 (ponderosa pine per cent) −0.7740 (sugar pine per cent) −0.9398 (Douglas fir per cent) −1.0704 (white fir per cent) −0.8427 (incense cedar per cent) −1.1996 (red fir per cent) +128.7553.

STATISTICAL MEASURES

The various statistical measures employed in the computations are given in Table 16.

TABLE 16.—*Statistical measures*

Dependent variable (per cent)	Alienation index	Correlation index	Standard error of average table	Standard error of average table and regression equation combined	Average percentage deviation [1]	
					From average table only	From average table and regression equation combined
			Per cent	*Per cent*	*Per cent*	*Per cent*
Total basal area	0.2486	0.9686	26.24	6.52	21.0	5.22
Number of trees	.6926	.7213	32.19	22.29	25.8	17.8
Volume, cubic feet	.7442	.6680	27.52	20.48	22.0	16.4
Volume, board feet	.7224	.6915	36.46	26.34	29.2	21.1

[1] Average percentage deviation $=\frac{\text{standard error.}}{1.25}$

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AN ANALYSIS OF LOG PRODUCTION IN THE "INLAND EMPIRE" REGION

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TECHNICAL BULLETIN No. 355 JUNE, 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

AN ANALYSIS OF LOG PRODUCTION IN THE "INLAND EMPIRE" REGION

By M. BRADNER, *in charge Office of Forest Products, Northern Rocky Mountain Region;* F. J. KLOBUCHER, formerly *Forest Examiner;* J. W. GIRARD, *Logging Engineer, Division of Forest Economics, Branch of Research;* and S. V. FULLAWAY, JR., formerly *in charge Office of Forest Products, Northern Rocky Mountain Region, Forest Service.*[2]

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INTRODUCTION

The importance of logging, or the complete task of handling logs from standing timber to the sawmill or common carrier, is indicated in the enormous annual log output of the Nation. It is estimated that between 35,000,000,000 and 40,000,000,000 board feet of timber is taken out each year in the form of log-sized material. Furthermore, the logging end of the operation in this region actually

[1] The "Inland Empire," which is considered as forming a distinct lumbering region, may be defined for the purposes of this bulletin as including the forested areas in western Montana, Idaho north of the Salmon River, eastern Washington tributary to Spokane, and the northeastern tip of Oregon.

[2] The studies forming the basis of this bulletin were started by Girard in 1919. The collection of the bulk of the field data was made by Girard and Klobucher. Fullaway, while in charge of the office of forest products in the northern Rocky Mountain region, assisted materially in the supervision of the project and in the revision of the original report covering the results of the studies. Bradner prepared the final report for publication, adding to the original work the results of later studies.

The authors wish to acknowledge their indebtedness to all who have aided in any way the accomplishment of this work, particularly to P. Neff, who has helped much in the collection of the data and the checking of results; to Clyde Webb, T. Crossley, R. Williams, R. Ellis, J. E. Keach, A. R. Standiford, R. Woesner, K. A. Klehm, O. A. Knapp, H. Regnes, and I. V. Anderson, now or formerly Forest Service Officers, for the actual collection of field data; and to the Anaconda Copper Mining Co., the Polleys Lumber Co., Beardsmore Lumber Co., Henry Good Logging Co., Whaley Bros. Logging Co., Smith Bros. Logging Co., Baird-Harper Lumber Co., Potlatch Lumber Co., Bonners Ferry Lumber Co., Deer Park Lumber Co., Rose Lake Lumber Co., P. L. Howe Lumber Co., Dalkena Lumber Co., Edwards-Bradford Lumber Co., McGoldrick Lumber Co., and the J. Neils Lumber Co., for the help and cooperation extended in making the studies on their logging operations.

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involves about half the total actual cost of production from the stump to the finished product. The best logging methods are accordingly of first importance.

Logging engineering has developed remarkably during the past decade. There has never been, however, a time in the history of the lumber industry when the need for progress in this field was more pronounced than it is to-day. Logging in virgin timber has steadily progressed into the less-accessible and lower-quality stands, and the stumpage value has in general become increasingly higher. The big consuming centers are at great distances from the principal producing regions. Other materials have made substantial inroads upon lumber markets and competition between lumber-producing regions has been greatly intensified by overproduction. Requirements for capital investments and production costs all along the line from stump to finished product are generally increasing. Industrial progress generally, as well as severe competition within the lumbering field, now points to the necessity for the lumber industry to follow the lead of other great industries and place its operations on a sounder basis.

The task of selecting the best method of operation to insure a profit involves more considerations in logging than in most industries. Logging is done under operating conditions which vary constantly. Each individual chance or logging unit, however small, presents a different problem for solution. Further uncertainty is added through the influence exerted by the weather and other natural factors. Owing in part at least to this uncertainty, the successful logger of the past developed considerable resourcefulness. In his decisions, however, he was guided largely by personal experience. The type of improvements, the kind of equipment, the operating methods, and the standard of utilization have quite commonly been adopted upon the personal recommendation of one man. Records of past experience were seldom if ever kept in such form that the information they contained could be applied to other operations.

With the gradual development of logging engineering in recent years, the lumber industry has made marked progress in the use of recorded experience. Personal knowledge and judgment are now qualified and greatly influenced by actual records of past performance and results. Nevertheless, it is still quite widely believed that organization and management in logging are largely matters of personality and personal judgment. There can be no doubt that these factors must continue to be essential in all industry, but in common with all other lines of endeavor, the planning and conducting of logging operations will become less haphazard and uncertain as basic facts are accumulated and come into use and rule-of-thumb methods are displaced by methods that rest more upon recorded facts and less upon personal judgment.

A very material step toward the development of systematic logging methods has been made possible in the "Inland Empire" through a comprehensive investigation of logging output by the Forest Service. Records of actual accomplishment have been obtained for the common methods of operation under a uniform classification of the natural conditions usually encountered. These

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records afford a means of accurately and conveniently measuring or estimating performance or productivity. In contrast to the usual cost data, such records have the advantage of permanent value. Being based upon specific conditions, these records are applicable to such conditions wherever found. Thus, these logging-output studies constitute a new and significant departure in the logging-engineering field.

The primary purposes of this bulletin are to present the results of these "Inland Empire" logging-output studies, to analyze the effect of the various factors upon output, to explain their use, and to demonstrate the practical value of such data. Very definite principles and methods are necessarily involved in making logging-output studies. A knowledge of these is essential not only for the proper conduct of such studies but to permit the most intelligent application of them. For this reason a section of the appendix is devoted to a discussion of the principles and methods involved.

Logging-output studies furnish information of permanent value. Such data can be converted readily and accurately to a dollar or cost basis by the application of current wage scales and costs, and form, therefore, a reliable means of estimating the cost of logging. As a result they can be put to practical use in the appraisal of stumpage values, in bringing about better logging methods, in the intelligent letting of contracts, and in determining sound and profitable utilization standards.

Output records, in conjunction with a detailed examination of conditions on the ground, afford the means of determining the most logical plan of operation and the best means of accurately appraising operating costs. A knowledge of these costs, quite as much as of manufacturing costs and selling value, is essential to the establishment of a proper stumpage value. Output records also enable the operator to make a true comparison of the actual merits of the different kinds of improvements, equipment, and methods for each logging chance, and thus assure the most efficient and economical operation. They make it possible to check the output of men or machines with the normal output, so that contracts to meet specific conditions may be let upon an intelligent basis.

The profitable cutting size and limit of defect in a stand of timber can be determined only from detailed and accurate data such as are obtainable in logging-output and milling studies. Through the application of such cutting limits not only is a more profitable operation possible, but the selection cutting resulting therefrom usually leaves the area in a more productive state. This is the first step in good forestry practice.

SCOPE AND NATURE OF THE OUTPUT STUDIES

The studies of logging output made in the "Inland Empire" region by the Forest Service from 1919 to 1928, inclusive, have covered all of the several important timber-type classifications of this region for both the winter and summer logging seasons. The bulk of the field data forming the basis for this report was collected during the first five years of this period. These data are supplemented by further logging-output studies conducted since 1923. A

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number of studies covering all phases of tractor logging from stump to landing in the ponderosa pine type were made in 1928. The volume of timber handled in the various branches of the logging operation covered by all of those time and output studies is as follows:

	M. ft. b. m.		M. ft. b. m.
Sawing	3,206	Dray hauling	840
Horse skidding	7,483	Sleigh hauling	2,146
Tractor skidding	4,663	Autotruck hauling	1,441
Donkey skidding	773	Trailing in chutes	1,917
Loading sleigh	222		
Loading autotrucks	765	Total	23,456

Studies have been limited to sawing, skidding, trailing in chutes, loading on sleighs and autotrucks, hauling, and slash disposal. All of these steps in the logging operation come between the stump and the landing—where a large share of the log cost usually occurs and furthermore where errors of judgment are most likely to prove very expensive. Moreover, the factors which appreciably affect the output in these phases of the logging operation are readily distinguished and classified both at the time of study and in the subsequent application of the data.

Operation in some branches of the work, such as railroad and flume transportation, is so well standardized that data of sufficient accuracy are available from cost accounts. Moreover, in these branches output depends largely upon independent influences such as demand for logs and the output in other branches of the operation. The same is true of "tailing down" on landings and decking logs. Output studies in these branches have therefore been excluded.

No attempt was made to give any indication of the relative efficiency of individual workmen, units of organization, or equipment. This was not the object in view. Once an average representing the output of a number of units crews is made available, however, it becomes a good yardstick with which to measure the work of other men or machines on similar jobs. The variation due to the human element in individual crews has not been studied. So far as possible this influence has been eliminated by securing records for a large number of men or crews selected at random.

In every other respect as well, the aim in these studies has been to obtain information which would be of general use in the region, represent average results obtainable, apply to specific conditions, and be as nearly permanent as possible.

In the woods, output data were collected only from crews of standard size. Only those men whose work directly affected the output of the unit organization were considered as part of the crew. The work of a large number of unit crews or machines, irrespective of their relative efficiency, was followed.

The output data were collected under definite classifications as to the natural conditions found on the different areas. Of these conditions the species or forest type, size of timber, slope, and season of the year exert the greatest influence upon logging output and therefore were adopted as the primary classification elements. Height of trees, stand per acre, windfall and undergrowth, and surface, although recognized in the collection of data as affecting output in varying degrees, were considered of minor importance.

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Distance, gross volume, and time were the basic units of measurement used. Distance, when a factor in output (as in skidding with horses), was always taken as the actual distance along the slope under load and not the horizontal distance. Gross scale by the Scribner decimal C log rule was used as the unit volume of measurement for all branches of logging, since, if net scale had been used, the data would have been applicable only to stands containing the same percentage of defect. Where it is desired to determine output or cost for any particular stand of timber, the estimated percentage of defect in that stand may be applied to the gross scale.

Only actual working time plus any normal lost time is included in job measurements. For example such time is excluded as that lost by a skidding team because of a filled skidway, or that chargeable to any other branch of logging work but skidding itself. Actual working time includes such time as is lost in resting, minor repairs of equipment, or overcoming any other difficulties encountered in actually doing the work—such as hanging up a tree in sawing. Where teams were doubled up to skid a large log, the trip time was doubled.

The hour was adopted as the standard unit for measuring the labor used on the job. The use of the effective hour as a unit, in contrast to the day or dollar, avoids the complexities which otherwise result from constant fluctuations in wages and the length of the working day as, for instance, where travel from camp to the job is on company time and must be deducted from the standard day before effective hours can be arrived at. In using the output data as here presented it is necessary only to apply the output per hour to the estimated number of effective hours which it is possible to put in on the job.

The refinement justified in time and output studies of any kind of work is dependent largely upon the variations found in the working conditions. It is of no practical value to determine the individual effect on output of factors which can not be controlled. The degree of detail necessary to make certain that the data on any particular unit crew or piece of equipment represent the average performance depends upon how consistent the crews are in their work, the nature of the conditions under which the work is done, and the range over which the figures must be distributed. More data are necessary when the logs are skidded on the ground by horses than when trailed in chutes, since the improvements in the latter case have more nearly standardized working conditions. Undoubtedly the greatest variations occur in work into which the human element enters to the greatest degree. A full discussion of the refinement justified and the amount of information necessary to assure average data in these studies is given in the appendix.

LOGGING-OUTPUT GRAPHS AND THEIR USE

The actual output data for the different branches of logging are presented in the form of graphs for all activities except swamping and slash disposal; these are given in tabular form. The studies include the following steps in the operation in the order in which they are presented: Sawing (including felling and bucking in the woods, felling, limbing and topping, and bucking on the landing);

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skidding (horse, tractor, donkey engine, and big wheel); loading and unloading; transportation other than skidding (including trailing in chutes and hauling on drays, sleighs, and autotrucks); and swamping and slash disposal.

A discussion of the factors affecting output, together with facts pertinent to the understanding and specific use of the graphs, accompanies each set of data. In order to facilitate the use of the graphs in determining operating costs, a number of examples or problems and their solution are given for each branch of logging studied. Output or cost can be determined to a finer degree than that indicated here by interpolation between the values shown. Even where existing methods and conditions do not fall within the range of the data presented, the information here given will often be of value as a general guide to, or an indication of, what might be accomplished.

Certain very definite principles or basic facts about logging must be fully understood before output data of the type presented can be used effectively. The influence of defect in timber is reflected as a uniform flat reduction in the quantity of output in all ends of the logging work. There is no appreciable difference in output between defective and sound material on the basis of gross-scale volume. The amount of work involved in handling two logs of similar size, one sound and the other one-half defective, is practically the same. The actual net output in the case of the defective log would, therefore, be one-half that of the sound log.

Breakage reduces sawing output but increases that of all other parts of the operation from stump to mill pond, since the greatest percentage of breakage occurs in the small-top logs. The elimination of these from the run increases the average size of the log cut from the stand.

The size factor which determines output in all branches of the operation except sawing is the scale of the log rather than the dimensions from which that scale is derived. If two logs, one 20 feet and the other 12 feet in length, each scale 140 feet, practically the same output will be obtained from both. On the standard 16-foot length basis, however, one would run 9 logs and the other 5½ logs per thousand feet board measure. Therefore, by cutting a stand of timber which averages 10 logs per thousand into logs 24 feet long, an output would be obtained approximately the same as that from a stand running seven 16-foot logs per thousand. This same ratio will not hold in sawing. Cutting 10-log material into 24-foot lengths gives an output far above that for 7-log material cut into 16-foot lengths.

Overrun is in reality a makeshift used to arrive at actual lumber contents when the scale rule fails to record actual contents, as it does most signally in the measurement of small logs. It will be used in connection with an attempt to determine the marginal log material which can be profitably handled.

An accurate timber estimate and a topographic or drainage map are essential to the most effective application of the data shown in the graphs in evaluating stumpage or determining the best methods of operation for a particular logging chance. Thus, after a careful examination of the area, the logging engineer with these aids, has all the facilities necessary to arrive at very definite conclusions as to

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the best methods and the cost of these methods. This presumes, of course, that the appraiser has experience, judgment, and initiative, and is willing to put the data to their best use.

ANALYSIS OF SAWING-OUTPUT DATA

The output data for sawing are presented graphically in Figures 1 to 13, which are summarized in Table 1. The output per effective hour gross scale is based upon the work of two men and is determined both by diameter breast high groups and number of logs per thousand board feet of timber cut. A 2-man saw crew is the standard crew for either day or contract work. All output curves are, unless otherwise designated, applicable to jobs where the average log is approximately 16 feet in length. This is the approximate average length of all short logs cut in this region.

EFFECT OF NATURAL FACTORS ON SAWING OUTPUT

Natural factors which affect the sawing output, considered in the approximate order of their importance, are size of timber, species of timber,[3] season of the year, defect in timber, and slope, windfall, and undergrowth.

Sawing output up to certain sizes is influenced to a greater degree by the diameter of the timber than by any of the other natural factors affecting it. This influence is evident in every set of data where output is given according to size. In general, there is a fairly rapid increase in the output per saw crew per hour for each 2-inch diameter increase in the size of the trees cut, from the smallest trees on which data were obtained up to those 30 to 40 inches in diameter breast high.[4] Somewhere within these diameter limits, depending on the species cut, a point is reached where for several diameter sizes the output of the crew does not increase as the size of the timber increases. From this point on, as still larger trees are cut, the output per hour gradually falls off. This does not follow, however, with logs of unusual length. (Fig. 13.)

The curve in Figure 1 shows the output per crew (working on a day basis) per hour for western white pine to be 470 board feet for 12-inch trees (diameter breast high), 940 board feet for 20-inch trees, and 1,210 board feet for 28-inch trees. The maximum output per crew per hour under the condition as described on the graph (1,270 feet board measure) was reached in sawing trees 34 to 36 inches diameter breast high. Logs from western white pine trees of these sizes would run from three and one-half to three logs per thousand. From this point on, the output of the saw crew decreased as the size of the trees cut increased. The curve shows an output per saw crew per hour of 1,200 board feet for the 44-inch tree, the largest diameter group for which data were obtained. Practically the same output

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[3] The commercially important tree species referred to in this bulletin are:

Botanical name	Accepted common name	Trade name
Pinus monticola D. Don	Western white pine	Idaho white pine.
Pinus ponderosa Laws	Ponderosa pine	Ponderosa pine.
Larix occidentalis Nutt	Western larch	Larch.
Pseudotsuga taxifolia (LaM.) Britt	Douglas fir	Douglas fir.
Picea engelmannii Engelm	Engelmann spruce	Spruce.
Abies grandis Lindl	Lowland white fir	White fir.
Tsuga heterophylla (Raf.) Sarg	Western hemlock	Hemlock.
Thuja plicata D. Don	Western red cedar	Cedar.

[4] D. b. h.=diameter, breast high, or 4½ feet above ground, measured outside (including) bark.

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TABLE 1.—*Index to sawing graphs*

Fig. No.	Forest type	Slope	Species	Stand per acre	Season	Surface conditions				Method	Labor
						Brush	Windfall	Surface	Snow depth		
		Per cent		*M.ft.b.m.*					*Inches*		
1	Western white pine	0–30	Western white pine	10–20	Winter	Medium	Medium	Smooth	20	Felling and bucking	Day.
2	do	30–50	Western white pine and white fir, larch, Douglas fir, cedar.	25	do	Light to medium	Light	do	0–40	do	Contract.
3	do	30–50	Western white pine type.	25	do	do	do	do	12–15	do	Three contract crews.
4	Ponderosa pine	0–30	Ponderosa pine	8–12	Summer	Light	do	do		do	Day and contract.
5	do	0–30	Douglas fir	10–12	do	do	do	do		do	Contract.
6	Larch, Douglas fir	0–30	Larch		Winter	Light to medium	do	do	18	do	Day.
7	Ponderosa pine	0–30	do	10–12	Summer	Light	do	do		do	Contract.
8	Engelmann spruce	0–15	Engelmann spruce and balsam fir.		do	Medium	do	do		do	Do.
9	Western white pine		Western white pine and white fir.		Winter					Bucking or landing	Do.
10	do	15–50	Western white pine and white fir, larch, and Douglas fir.	15	do	Medium	Medium	Smooth	30–40	Felling and topping	Do.
11	Ponderosa pine	15–50	Ponderosa pine	10	Summer	do	Light	do		do	Do.
12	do		do		do					Bucking on landing	Do.
13	do	20–45	do	10	do	Light	Light	Smooth		Felling, limbing, and bucking into long logs.	Do.

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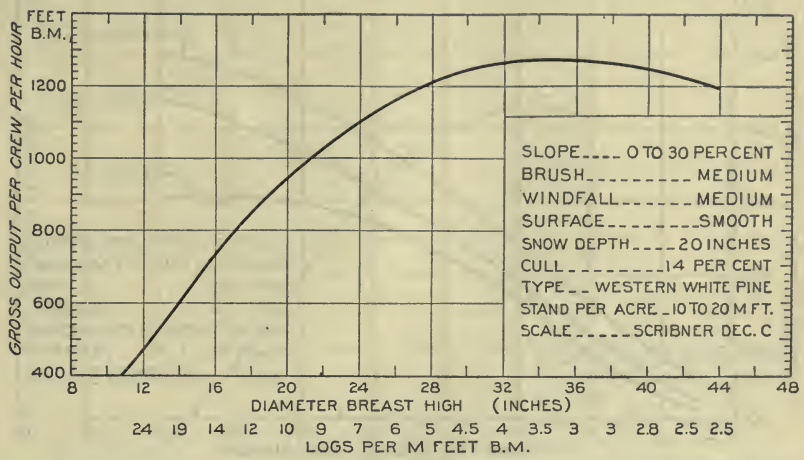

FIGURE 1.—Sawing output (felling and bucking) in western white pine; day labor. Basis, 262 M feet, 205 trees. Data collected December, 1919, and January, 1920

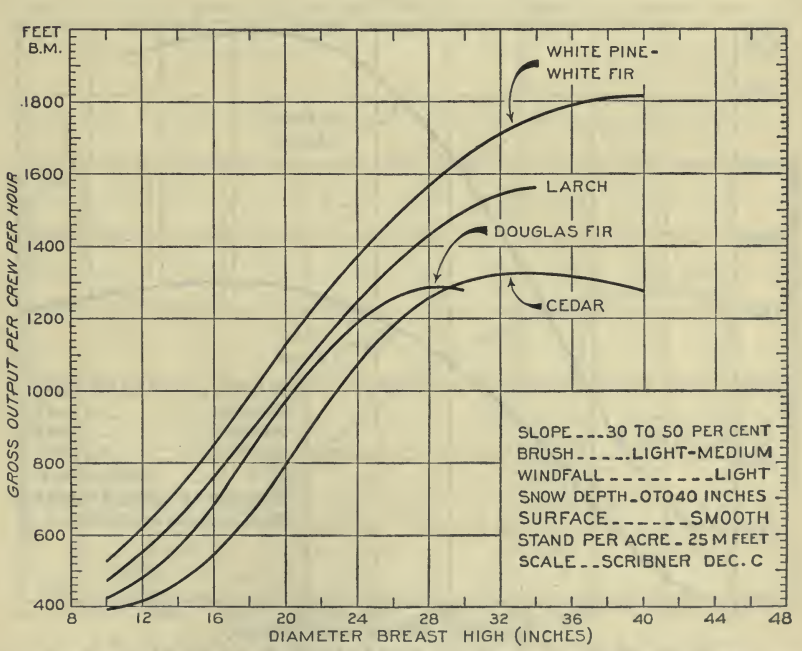

FIGURE 2.—Sawing output (felling and bucking) in western white pine; contract labor. Basis, western white pine and white fir, 600 M feet, 643 trees; larch, 95 M feet, 167 trees; Douglas fir, 48 M feet, 88 trees; western red cedar, 84 M feet, 117 trees. Data collected December and January, 1921

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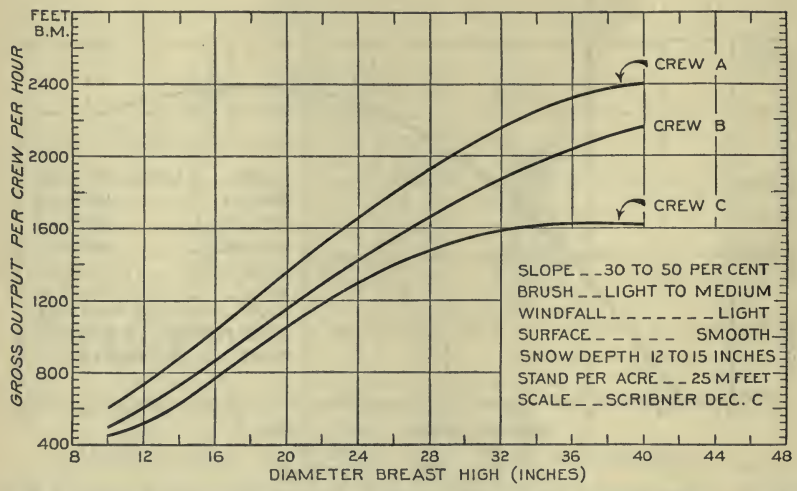

FIGURE 3.—Comparative sawing output (felling and bucking) in western white pine type, under the same conditions, of three different contract saw crews, paid on thousand-feet basis. Data collected December and January, 1921

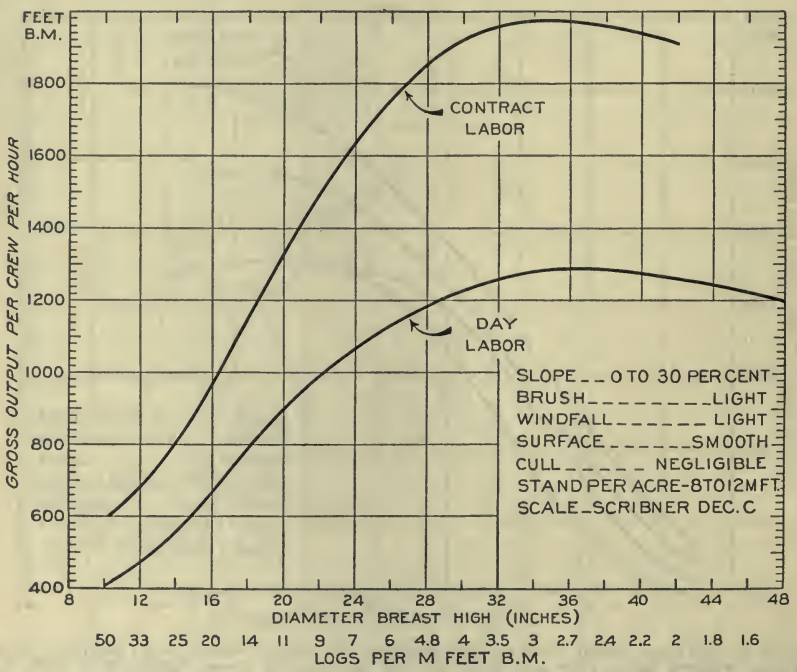

FIGURE 4.—Comparison of sawing output (felling and bucking) in ponderosa pine under day and contract basis. Basis, day work, 413 M feet, 500 trees; contract work, 171 M feet, 204 trees. Data collected summers, 1919 and 1920

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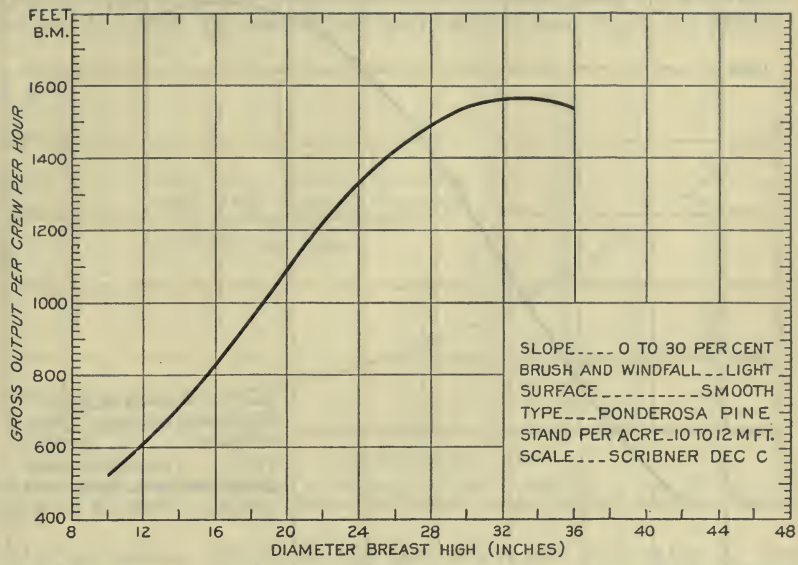

FIGURE 5.—Sawing output (felling and bucking) in Douglas fir, contract labor. Basis, 51 M feet, 203 trees. Data collected summers, 1919–1920

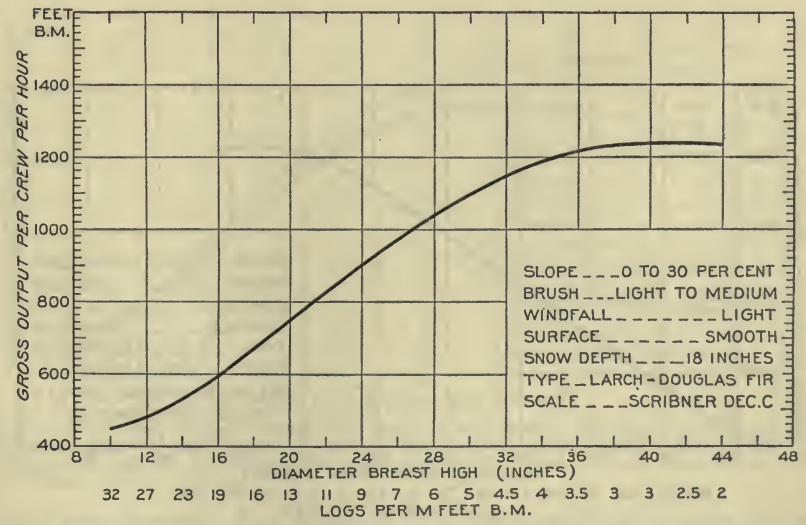

FIGURE 6.—Sawing output (felling and bucking) in western larch, day labor. Basis, 496 trees. Data collected January and February, 1921

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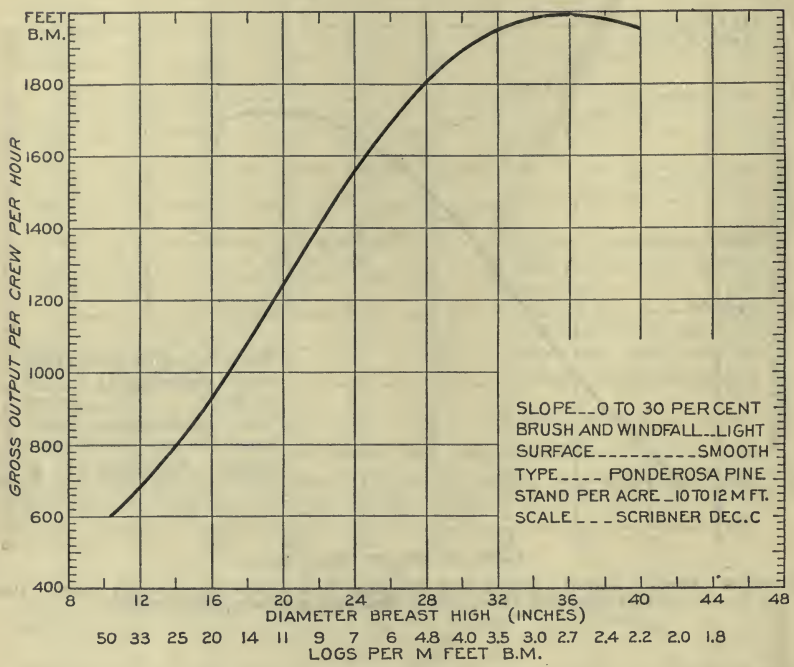

FIGURE 7.—Sawing output (felling and bucking) in western larch, contract labor. Basis, 87 M feet, 141 trees. Data collected summer, 1920

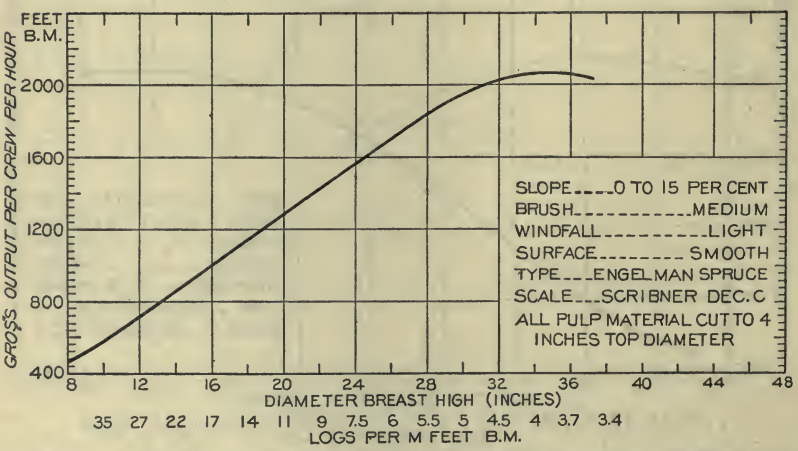

FIGURE 8.—Sawing output (felling and bucking) in Engelmann spruce and balsam fir, contract labor. Basis, 147 M feet, 478 trees. Data collected August, 1922

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was obtained by the crew when sawing 28-inch trees. The day-work sawing curve in Figure 4 shows that in ponderosa pine the maximum output per saw crew per hour was obtained when trees 36 to 38 inches diameter breast high were felled and bucked into logs. In Douglas

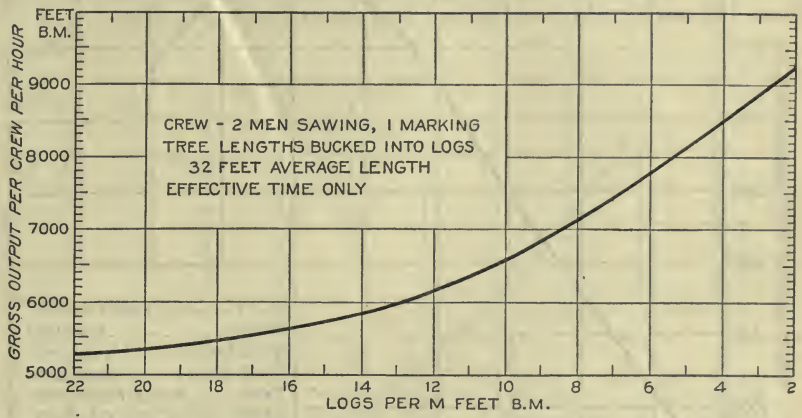

FIGURE 9.—Sawing output (bucking on landing for donkey skidding) in western white pine and white fir, contract labor. Basis, 125 M feet. Data collected January–February, 1921

fir the maximum output of the saw crew per hour (fig. 5) was reached in cutting 32-inch trees; in western larch (fig. 7) in 36-inch trees.

The relatively low output of a saw crew operating in small timber is in great part due to the extra number of trees which must be felled and bucked in order to obtain a scale equal to that resulting where

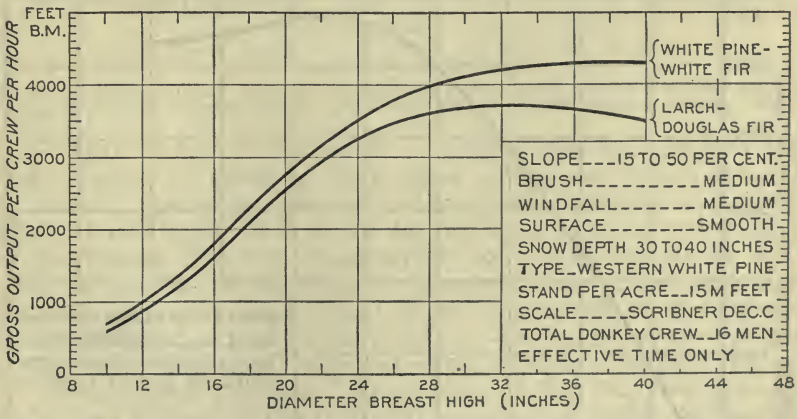

FIGURE 10.—Sawing output (felling and topping for donkey skidding), contract labor. Effective time was 60 per cent of total, lost time being due to felling but one load in advance of skidding to changing line, etc. Basis, 300 M feet. Data collected January–February, 1921

larger trees are cut. Sawyers cutting western white pine trees which average 14 inches diameter breast high and run four and one-half logs to the tree would have to fall and buck four such trees to obtain an output of approximately 1,000 board feet gross log scale. Approximately the same could be obtained by felling and bucking one 25-inch

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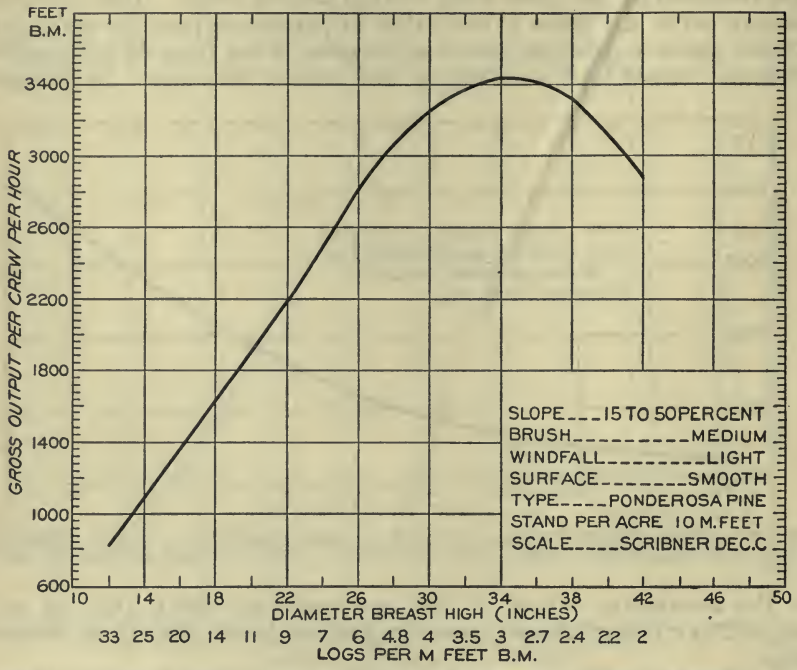

FIGURE 11.—Sawing output (felling and topping for tractor skidding) in ponderosa pine, contract labor. Basis, 263 M feet. Data collected August-September, 1928

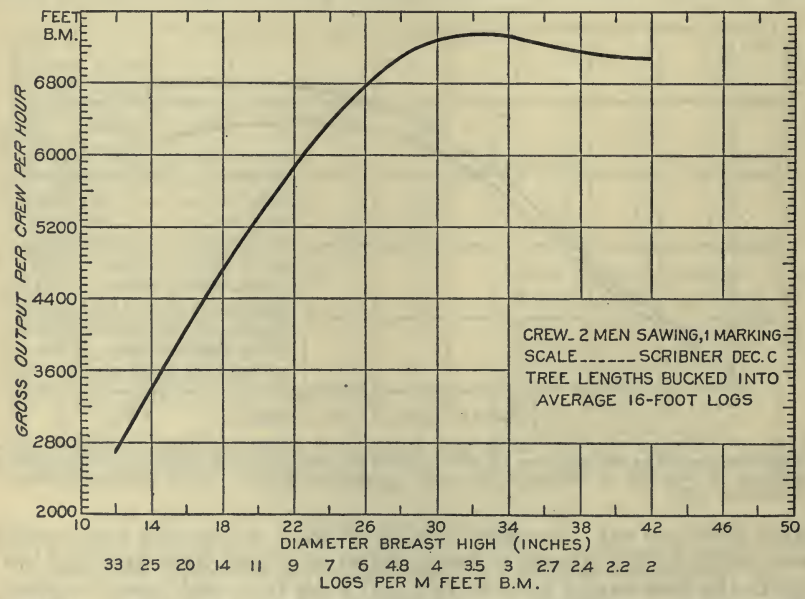

FIGURE 12.—Sawing output (bucking on landing for tractor skidding) in ponderosa pine, contract labor. Basis, 128 M feet. Data collected August, 1928

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7-log tree. A large percentage of the total time consumed in the sawing operation is spent in going from tree to tree, brushing out around the tree,and sizing it up, and in the actual felling. Some effective time is lost in the short rest period which often follows the completion of the felling and bucking-up of each tree. The time thus lost is much less per thousand for large timber than for small timber.

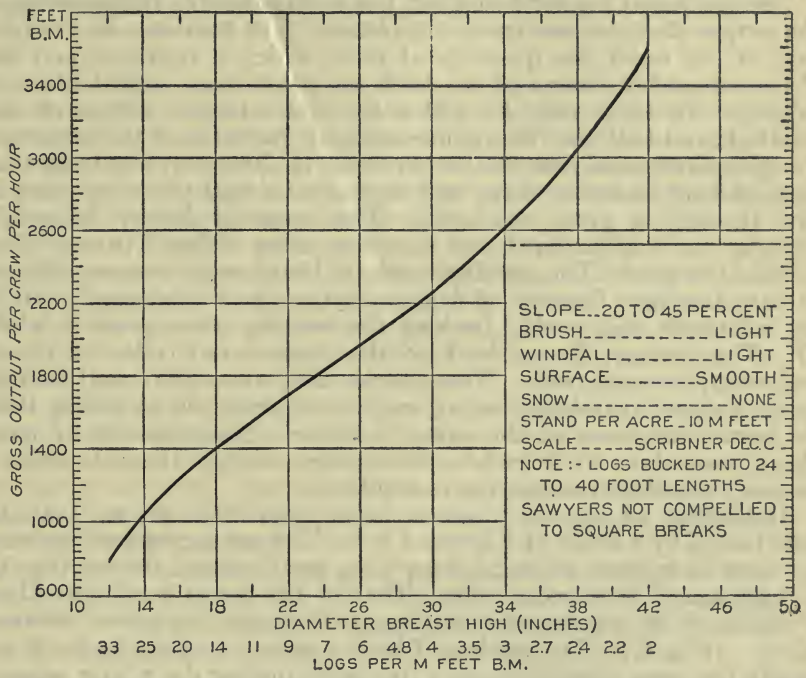

FIGURE 13.—Sawing output (felling, bucking, and limbing three sides for tractor skidding) in ponderosa pine, contract labor. Basis, 182 M feet. Data collected October, 1928

In actual surface to be sawed in felling, the four 14-inch trees would require 1.3 times as much labor as the one 25-inch tree. In the bucking operation, however, although there would be approximately 18 cuts to be made in the 14-inch trees as compared with but 7 in the 25-inch tree, the actual surface to be sawed would be less.

The decrease in output with an increase in size of the trees above 32 to 36 inches diameter breast high (depending on the species) can be attributed in part to three factors—the length of the standard saw used, the additional physical effort necessary to pull the saw, and the increased breakage. The length of the standard saw commonly used in cutting the relatively small-sized timber of the "Inland Empire" is 5½ to 6 feet. This and the 7-foot saw are well adapted to the size of timber normally found. It is possible that a longer saw is needed for more efficient work in timber 36 inches and over in diameter. It has been noted that where exceedingly large cuts are being made the 6-foot saw can be operated to advantage by only one of the sawyers.

Large timber, because of its excessive weight and height, breaks and splits more readily when felled, and the breaks are usually

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farther down in the tree than in smaller timber. In bucking the tree into logs, these breaks must be sawed out, and this means from one to several extra cuts of large diameter for the saw crew. Large trees often partly bury themselves in the ground when felled, thus adding to the difficulty of bucking them into logs. There are no other obvious reasons for the decreased output beyond a certain diameter, which is approximately the same for all species.

The species of timber being cut has a considerable influence upon the output that the saw crew will obtain. The hardness and toughness of the wood, the quantity of pitch which it contains, and the character and thickness of the bark are all factors which influence sawing. To these may be added the characteristic shape of the tree butt and bole, and the occurrence and character of the branches. Toughness of wood fiber is another cause of difficulty, requiring that saws be kept in better shape and that more actual power be used to saw through a given thickness. The wood of Rocky Mountain Douglas fir is quite hard and therefore more difficult to saw than that of the pines. The corklike bark of Douglas fir is more difficult to saw through, because of both structure and thickness, than is the relatively thin woody bark of the western white pine or white fir. The stringy, fibrous bark of the western red cedar strips off and clogs the saw teeth. Tree species that are often swell butted, such as western larch and cedar, require a thicker cut in felling than do even-boled trees of the same diameter. Some species of trees clean themselves of branches much more readily than do others, and as a result less swamping is required.

The effect of species characteristics upon the output may be ascertained by a study of Figures 1 to 8. The sawing output per crew per hour in western white pine for 9-log per thousand timber (fig. 1) is 1,025 board feet gross scale. That is 125 board feet more than is obtained by a saw crew cutting in 9-log per thousand western larch. (Fig. 6.) The sawing of both species was done under practically the same conditions, on a day basis during the winter season. The difference in output is no doubt due, to some extent, to the greater thickness of the larch bark and to the characteristic swell butt of this species. In the larger larch trees, long butting is often required; this necessitates an extra cut in bucking.

Figure 2 shows the output per hour for different-sized trees obtained by a contract crew cutting the several associated species in the white pine type. Output per crew per hour for 22-inch trees is 1,250 board feet in western white pine and white fir, 1,135 board feet in western larch, 1,085 board feet in Douglas fir, and 935 board feet in western red cedar. Thus the difference in output between western white pine and western larch obtained by the contract crew is 115 board feet per hour in 9-log per thousand timber, about the same difference as was shown in the output obtained by crews working on a day basis.

The difference in output in summer and winter work, expressed in terms of men and equipment required, is much less noticeable in sawing than in skidding or chuting. Seasonal changes influence sawing in only two respects—freezing of timber and depth of snow, in themselves variables. Frost in timber may be so slight that its effect is not discernable in the output; it may, on the other hand,

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be sufficient to cut down output as much as 50 per cent. The same may be said of the depth of snow. It does not hinder the work to an appreciable degree until it reaches a depth which makes its removal necessary in order to get down to the proper stump height in felling. These seasonal changes may take place by imperceptible degrees and will be reflected in output in a similar manner. The average effect of frozen timber and deep snow which may be anticipated in the "Inland Empire" region will not vary appreciably from the average represented by the curves based on winter sawing.

Defect in timber may result in either an increase or decrease in gross-scale sawing output. In certain stages of decay, wood acts as a serious impediment to the cutting speed of a saw, and gross output is materially decreased. This decrease is, however, about offset by the greater speed possible in sawing hollow trees or those containing dry rot, where the work is not obstructed.

Variables which have a minor effect on the output of the saw crew under average conditions in this region are slope, undergrowth, and windfall. Slope above 60 per cent, heavy brush, and windfall would of course greatly decrease the output. A certain degree of slope will add to the ease with which the felling operation may be performed, especially where the cutting of low stumps is required, but this advantage is generally offset by increased difficulties in bucking. After sawing starts, the surface soon becomes littered with felled trees and any interference from the brush and windfall is practically removed. Density of brush and degree of windfall are mentioned in the description of each sawing curve merely as indicative of the character of the stand.

In applying the sawing data to a particular job, the gross-scale output must be reduced by the estimated amount of breakage. Allowance for the probable percentage of breakage should be made during the preliminary examination of the logging chance.

OUTPUT BY DAY AND CONTRACT LABOR COMPARED

In addition to the natural factors which influence the sawing output, an important factor is the basis upon which the saw crew is paid. In this region sawing is done both by day labor and by contract.

It is a well-established fact that a man working on a piece or contract basis will attain a greater output per effective hour than if paid by the day to do the same job. Payment on the basis of the actual work performed is an incentive to greater achievement. Under the contract system, intelligently administered, personal ability, efficiency and hard work are rewarded. During the latter part of the World War and for several years following it, practically all parts of the logging operation were let on a contract basis. Payments were made for the number of thousand feet of logs sawed, skidded, chuted, loaded, or hauled, or at a contract rate per thousand or rod for chutes or roads constructed. The rate per thousand feet board measure or other unit was generally based upon what was considered a fair output per effective unit of time for an average worker or crew working on a day basis.

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The advantages of this system were, however, often lost by faulty application. Accurate records of past performance and results, if available at all, were seldom kept in sufficient detail to permit their use in determining a fair cost for any particular job. The difference in efficiency as between two individual workmen or two unit crews was not always given due consideration. The rate set in many cases was not based upon a fair output for an average crew. In far too many cases improper emphasis was placed upon the net daily earnings of the man or crew, and hard work and personal efficiency were penalized. The lack of accurate information upon which to base the contract rate resulted in considerable bickering and disagreement between the logging operator and his contractors. Lack of confidence in the cost records available or in his own personal judgment often caused the logging operator to change the contract rate a number of times when letting new contracts before the entire job has been completed. For a time contract logging fell into disrepute, and a number of logging outfits returned to the old method of operating on a day basis of pay. In late years there has been a gradual return to the contract method, especially in those branches of the logging operation where the factors effecting output are limited in number and their influence can be determined with comparative ease

Approximately 90 per cent of the sawing in this region is now being done on a contract basis, and payments are made either by the log or per thousand feet log scale. The output curves on all sawing graphs but Figures 1, 4, and 6 (and one curve on fig. 4) are based on contract work.

In Figure 3, in which the output for each of three different contract saw crews working under the same conditions is represented by a curve, it will be noted that there is a considerable difference in output between what may be classed as poor, average, and good saw crews. The size of the timber has a direct bearing upon these differences.

In felling and bucking trees averaging 14 inches diameter breast high the poor and the average saw crew differed but 90 board feet in output per effective hour. The difference is 140 board feet in sawing 24-inch trees and 420 board feet when the crews are cutting 36-inch trees. The same general increase, though more gradual, is found in the output differences between the average and good saw crews at the same diameter sizes. It is obvious that the larger the tree the more ability and technic are demanded of each member of the saw crew in felling it and the more important it is that the sawyers be accustomed to working together as a crew.

A comparison of the output obtained under day and contract work is shown in Figure 4 for ponderosa pine. The curves represent the output per crew per hour in board feet at each 2-inch diameter class from 10 inches to 48 inches, and the corresponding log per thousand groups. According to the curves, the contract crew obtains a greater output per hour by 300 board feet when sawing 20-log per thousand ponderosa pine than does the day crew. As the timber increases in size the difference in output between the two crews also increases. The contract crew attains 500 board feet more

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output per hour in sawing 9-log per thousand timber and 620 board feet more in 6-log per thousand timber.

HOW TO COMPUTE SAWING COSTS

The methods of using the graphs shown in Figures 1 to 13 is simple and practical. To apply them to a specific stand of timber or unit of a logging chance the procedure is as follows:

(1) Compute the average number of logs per thousand for the unit. Timber estimates are usually worked up in a manner to show the number of 16-foot logs per thousand by forties or natural logging units. In the ordinary stand of timber it is unnecessary to consider diameter classes separately. However, in stands, for example, having a large percentage of the volume in 14 and 16 inch trees and the remainder in 36 to 40 inch trees, separate consideration must be given to each group. In order to make the sawing data as easy of application as possible, output is as a rule given on the basis of both diameter and logs per thousand. It has been determined in these studies that a variation in height in the same diameter class does not materially affect the scale of the average log. Unless otherwise indicated in the descriptive caption of the graph, the data are applicable only where the average log length is approximately 16 feet.

(2) Determine the gross output per crew per hour for this computed size of timber from the graph which best fits the specific stand and operating conditions. Selection of the proper sawing graph to use to fit the specific chance requires much less experience than in other branches of the logging operation. There is but one kind of equipment with which to do the work in sawing. Slope, brush, and windfall have less effect. Distance from timber to landing needs no consideration. Reference to Table 1 will assist in the selection of the proper graph.

(3) Obtain the gross daily output by multiplying the gross output per hour by the number of hours which will actually be put in on the job each day.

(4) Obtain the net daily output by reducing the above figure by the estimated percentage of defect and breakage. The allowance for probable percentage of defect, breakage, and cull should be determined on the ground during the examination of the logging chance. The percentage of such deductions must be left entirely to the judgment of the man making the examination.

(5) Find the net cost of sawing per thousand by dividing the daily cost of the saw crew by the net daily output. A convenient form of saw-crew costs is shown in Table 13.

The two following examples are given to illustrate the proper use of the sawing graphs:

EXAMPLE A

To find the cost per thousand of sawing western white pine for the size of the timber and particular conditions:

The stand is of the white-pine type and will run 20,000 board feet per acre. The average western white pine tree in the stand is approximately 22 inches diameter breast high, and the timber will run 9 logs per thousand feet board measure. It is estimated as being

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about 7 per cent defective. The slope will average about 30 per cent, and the brush may be considered medium in density and size. The sawing is to be done in the winter, and it is estimated that there will be about 2 feet of snow on the ground at the time. The loss for breakage in felling may be considered negligible. Sawing will be done on a day basis, and it is planned to have the crews put in 8 effective hours per day on the job. The cost of the saw crew per effective day is figured at $9. This includes cost of files, oils, and a proportionate charge for time of the filer.

To find the sawing cost per thousand from the output data, proceed as follows:

Selecting Figure 1 as best fitting the specific stand and operating conditions, read the gross output per saw crew per effective hour for 9-log per thousand timber, or 1,025 feet board measure. The gross daily output per saw crew would then be eight times 1,025 feet board measure, or 8,200 feet board measure. To obtain the net daily output, reduce the gross daily output the estimated 7 per cent of defect (8,200 feet board measure reduced 7 per cent equals 7,626 feet board measure). To find the net cost per thousand, divide the daily cost of saw crew ($9) by this net daily output, obtaining $1.18 as cost of sawing per thousand.

EXAMPLE B

To find the cost per thousand of sawing ponderosa pine in a specific stand of timber:

The stand is of the ponderosa pine type running 10 to 12 thousand feet per acre and will fall into two distinctive size classes. Seventy per cent of the volume of the stand is made up of large mature trees 36 to 44 inches diameter breast high or 2.2 logs per thousand feet board measure. These trees are estimated to be 5 per cent defective. The loss from breakage in felling is estimated to be 3 per cent. The remainder, or 30 per cent of the volume of the stand, are young small trees 16 to 18 inches diameter breast high that should average 14 logs per thousand. This class of timber is practically sound, and the loss from breakage in felling is negligible. The slope averages 15 per cent and the brush is classified as light. The sawing is to be done on a day basis, during the summer season. The sawyers are expected to put in eight hours per day on the job, and the total cost of the saw crew per effective day is figured at $8.70.

To find the sawing cost per thousand from the output data proceed as follows:

Because of the wide variations in size of the timber, separate consideration must be given to the two size classes in figuring the sawing cost. Figure 4 (day-labor curve) is selected for use as it best fits the specific stand and operating conditions given in the example. According to the day-labor curve, the 2.2-log per thousand shows a gross output per saw crew per effective hour of 1,275 feet board measure. The gross output per effective hour for the 14-log per thousand timber is given as 785 feet board measure. The gross daily output per saw crew would be eight times the gross output per effective hour, 1,275 ft. b.m. × 8, or 10,200 feet board measure, for the large trees, and 785 ft. b.m. × 8, or 6,280 feet board measure, for the small trees.

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Reducing the gross daily output of the large trees by the estimated amount of defect (5 per cent) and breakage loss (3 per cent) gives a net daily output of 9,384 feet board measure. For the small sound trees no reduction need be made.

The net cost of sawing per thousand is then $8.70÷9,384, or $0.927 per thousand, for the large trees, and $8.70÷6,280, or $1.385 per thousand, for the small trees.

To find the weighted average cost of sawing per thousand in the stand, take 70 per cent (volume of large trees in the stand) of the cost of sawing the large trees and 30 per cent (volume of small trees in the stand) of the cost of sawing the small trees and add the results.

70 per cent of $0.927	$0.6489
30 per cent of $1.385	.4155
Sawing cost per thousand	1.0644

ANALYSIS OF SKIDDING-OUTPUT DATA

The output data for the several methods of skidding most commonly employed in the "Inland Empire" region are given in graphic form as follows: Horse skidding in Figures 14 to 26, tractor skidding in Figures 27 to 32, donkey (ground-line) skidding in Figures 33 to 35, and big-wheel skidding in Figure 36. These graphs are summarized in Table 2.

In contract skidding with horses the unit crew on which the output figures are based consists of the team and teamster and a swamper [5] who may also help in making up the trail of logs. Team and teamster is the standard unit in day work, although in some cases one-half the time of a chainer or dogger is included. Where the logging is all on a day basis the swamping is done as a separate job and usually is completed prior to skidding. All output curves for horse skidding are, unless otherwise designated, applicable to jobs where the average log cut is approximately 16 feet in length. This is the approximate average length of all short logs cut in this region.

Estimates for skidding with tractors ordinarily assume the use of a 10-ton machine with a crew of either one or two men besides the driver. Where the timber is skidded in tree lengths, a tractor unit crew usually consists of a choker setter and a swamper in addition to the driver. Any necessary swamping is done in conjunction with the skidding and is usually limited to brushing out around the felled trees so that the choker can be set speedily and without difficulty. Where the timber is skidded in long-log lengths, a team and teamster are used to bunch the logs in the woods; these then become part of the unit crew. The swampers, one or two in number, work with the bunching team and teamster.

[5] For definitions of logging terms see glossary, p. 85.

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TABLE 2.—*Index to skidding*

HORSE SKIDDING

Figure No.	Forest type	Slope [1]	Stand per acre	Season	Organization and equipment	Labor	Surface conditions: Brush	Surface conditions: Windfall	Surface conditions: Surface	Surface conditions: Snow depth	Size of timber
		Per cent	*M ft. b. m.*							*Inches*	*Logs/M*
14	Western white pine	0–15	10–20	Winter	1 chainer per team; tongs, chains, and dogs used.	Day	Medium	Medium	Smooth	10–30	3–26+
15	do	15–30	10–20	do	do	do	do	do	do	10–30	3–25
16	do	30–50	10–20	do	do	do	do	do	do	10–30	3–25
17	do	30–50	25	do	Team, teamster, and swamper; tongs and dogs used.	Contract	Light to medium	Light	do	24–40	3–17
18	Ponderosa pine	0–15	15	Summer	Team and teamster; tongs and chains.	Day	Light	do	Firm and smooth		3–25
19	do	15–30	15	do	do	do	do	do	do		3–25
20	do	30–50	15	do	1 chainer per 2 teams; tongs and chains.	do	Light to medium	do	do		3–26+
21	do	0–15	10	Winter	1 chainer per team; tongs and chains.	do	Medium	do	do	10–20	3–25
22	do	15–30	10	do	Team and teamster; tongs and chains.	do	do	do	do	10–20	3–26+
23	do	15–30	15	do	1 chainer per 2 teams; tongs and chains, small trees in whole lengths.	do	Light	None	Smooth	10–20	3–17
24	Larch-Douglas fir	0–15		Summer	Team and teamster; tongs and chains.	do	do	Light	Firm and smooth		3–17
25	do	0–15	10	Winter	1 chainer per 2 teams; tongs and chains.	do	Medium	do	Medium	10–20	3–26+
26	do	[2] 0–15	10	do	do	do	do	do	do	10–20	3–26+

TRACTOR SKIDDING

27	Ponderosa Pine	0–15	15	Summer	3 men, 10-ton tractor, whole tree lengths.	Day	Medium	Light	Smooth		1–17
28	do	15–30	20	do	2 men, 10-ton tractor, whole tree lengths.	do	Light	do	do		3–12
29	do	0–15	15	Winter	do	do	Medium	do	do	(3)	1–17
30	do	15–30	15	do	3 men, 10-ton tractor, whole tree lengths.	do	do	do	do	6–18	3–12
31	do	0–15	10	Summer	4 men and bunch team, 10-ton tractor, 24 to 40 foot logs.	do	Dense	do	do		3–26+

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32	do	[2] 0–15	10	do	4 men and bunch team, 10-ton tractor, short log.	do	do	do	do		3–12
					DONKEY SKIDDING (11 BY 14 INCH DONKEY)						
33	Western white pine	[2] 0–20	30	Winter	16 men; ground line	Contract	Light to medium	Light to medium.	Medium	30–40	3–12
34	do	0–20	30	do	17 men; ground line	do	do	do	do	30–40	3–17
35	do	[2] 20, 20	8	do	16 men; ground line	do	Light to heavy	Light to heavy.	do	30–40	5.5
					BIG-WHEEL SKIDDING						
36	Ponderosa pine	([4])		Summer	5 men, 2 sets wheels, 8 horses	Day	Light	Light	Medium		8

[1] Downhill unless otherwise noted. [2] Uphill. [3] Ground frozen. [4] Level.

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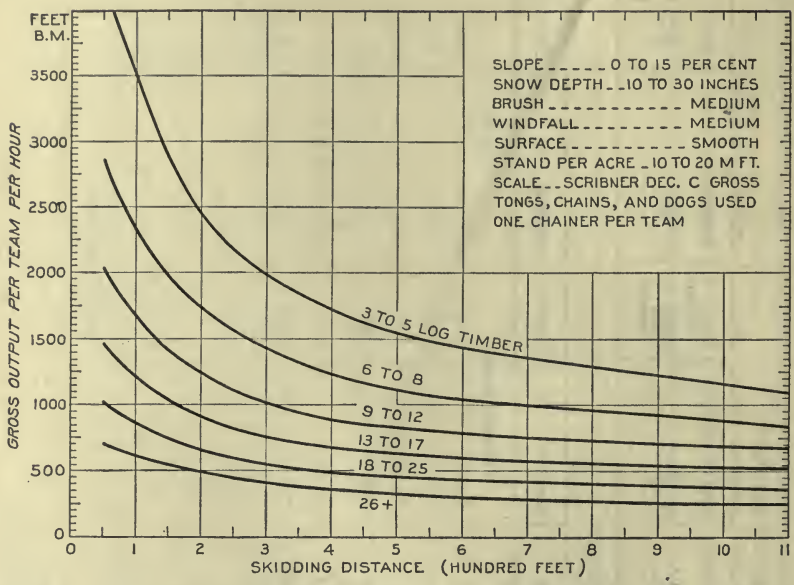

FIGURE 14.—Horse-skidding output, in western white pine type, little slope. Day labor, winter work. Basis: 770 M feet, 3,851 trips. Data collected winter, 1919, 1920, 1921, and 1922

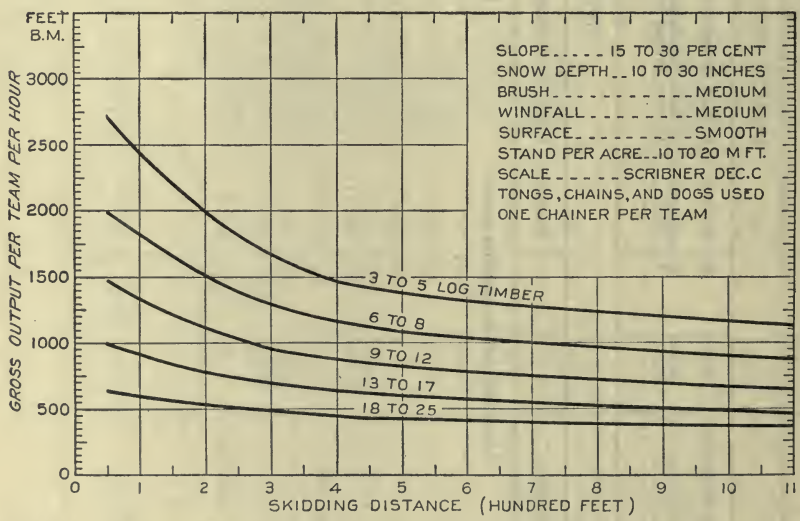

FIGURE 15.—Horse-skidding output, in western white pine type, moderate slope. Day labor, winter work. Basis: 976 M feet, 3,456 trips. Data collected winter, 1919, 1920, 1921, and 1922

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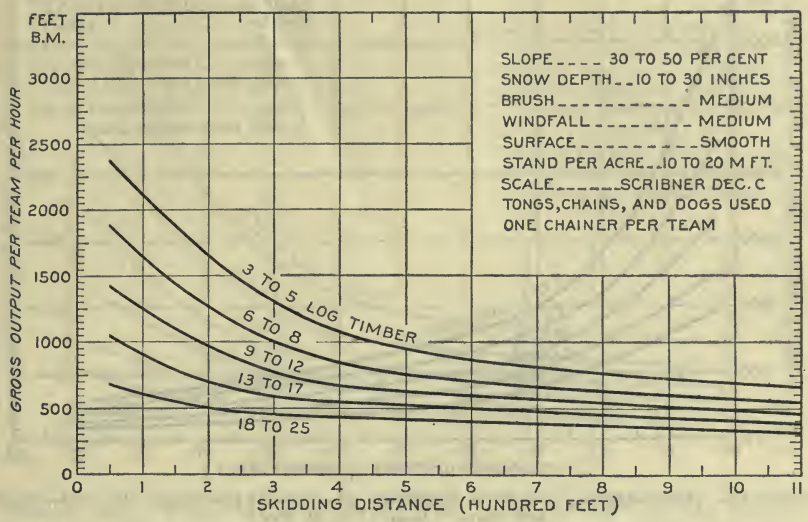

FIGURE 16.—Horse-skidding output, in western white pine type, steep slope. Day labor, winter work. Basis: 598 M feet, 1,610 trips. Data collected winter, 1919, 1920, 1921, and 1922

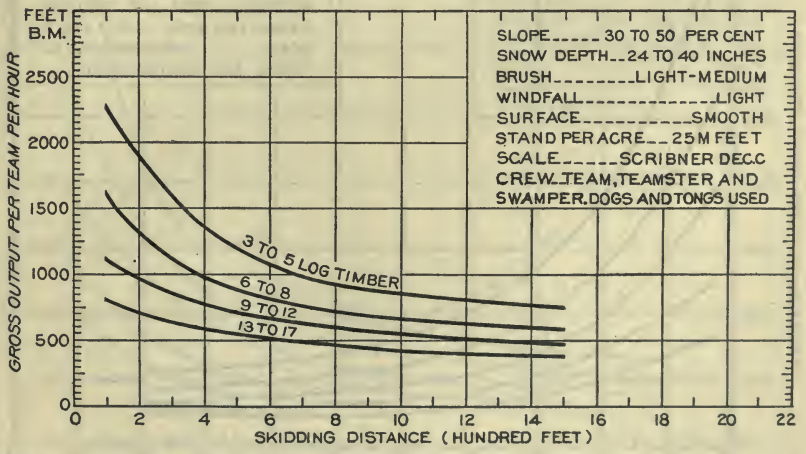

FIGURE 17.—Horse-skidding output, in western white pine type, steep slope. Contract skidding and swamping, winter work. Basis: 515 M feet. Data collected winter, 1921

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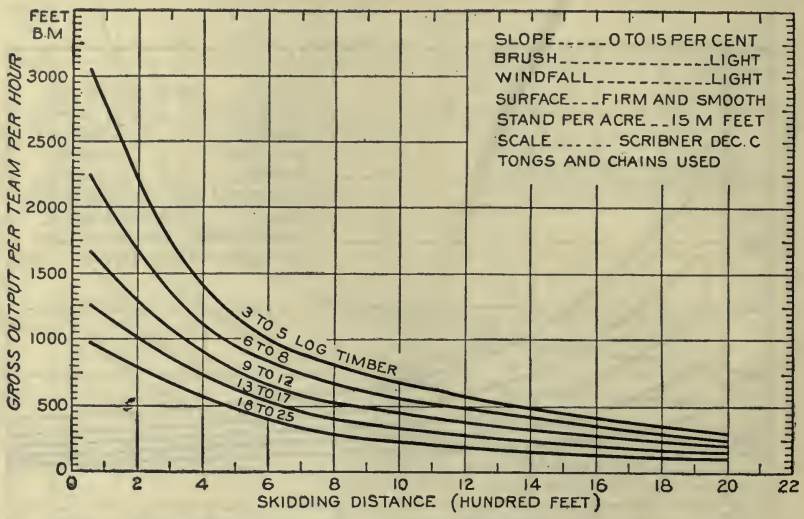

FIGURE 18.—Horse-skidding output, in ponderosa pine type, little slope. Day labor, summer work. Basis: 750 M feet

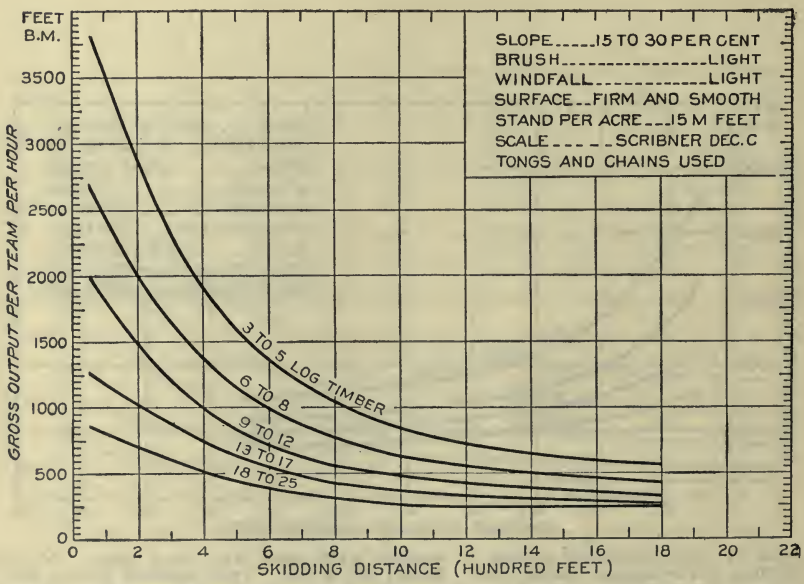

FIGURE 19. Horse-skidding output, in ponderosa pine type, moderate slope. Day labor, summer work. Basis: 198 M feet, 930 trips. Average scale per trip 213 feet. Data collected summer, 1919

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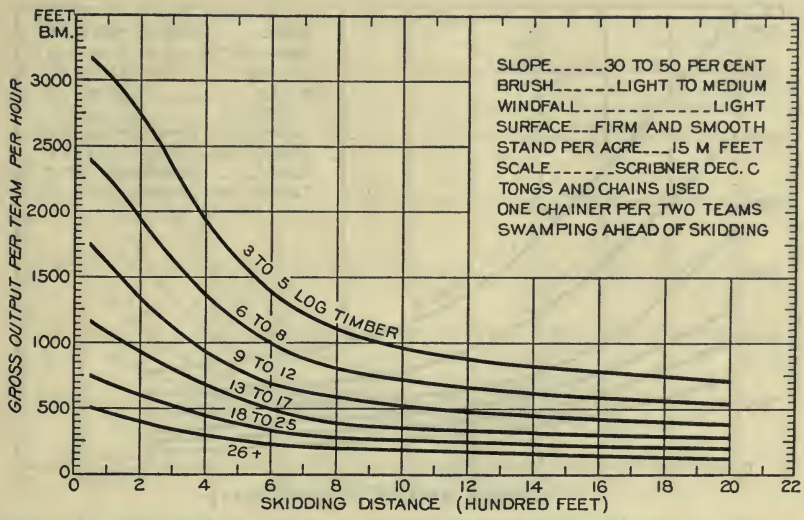

FIGURE 20.—Horse-skidding output, in ponderosa pine type, steep slope. Day labor, summer work. Basis: 491 M feet, 1,853 trips. Data collected July and August

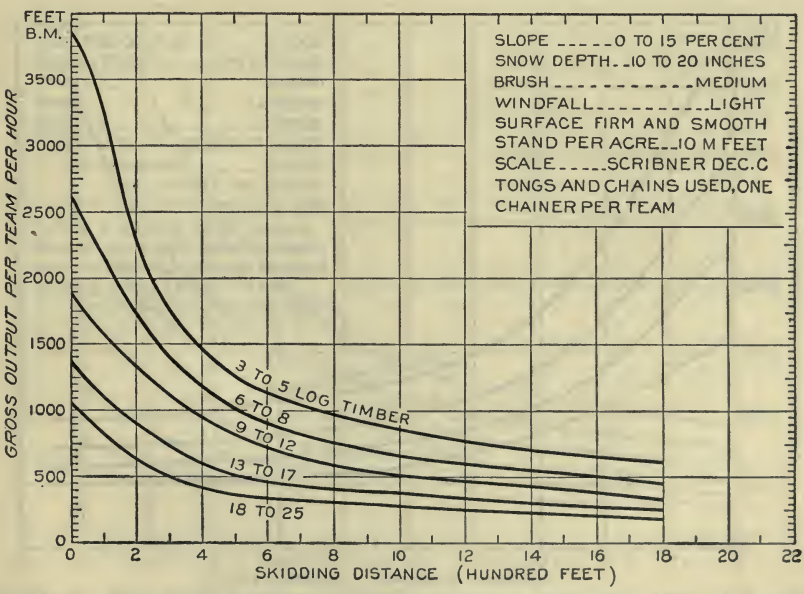

FIGURE 21.—Horse-skidding output, in ponderosa pine type, little slope. Day labor, winter work. Basis: 337 M feet, 1,500 trips. (Curves extended, beyond 1,200 feet distance.) Data collected December, January, and February

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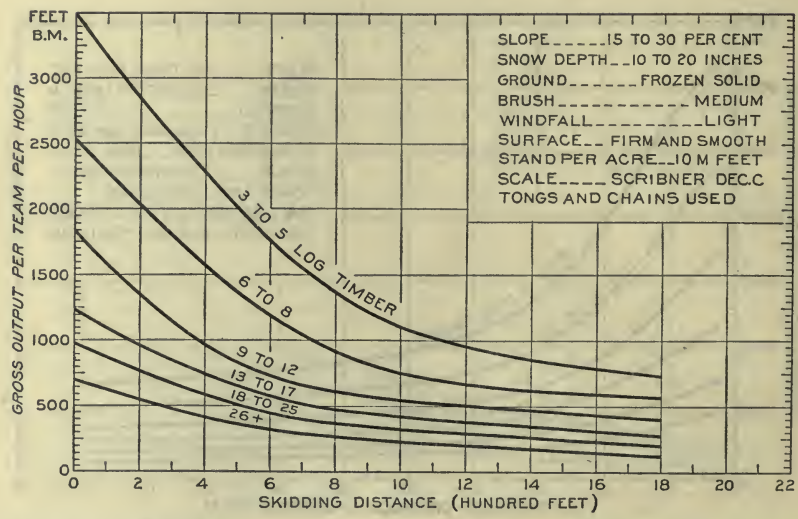

FIGURE 22.—Horse-skidding output, in ponderosa pine type, moderate slope. Day labor, winter work. Basis: 234 M feet, 1,100 trips. (Average scale per trip 213 feet.) Data collected December, January, and February

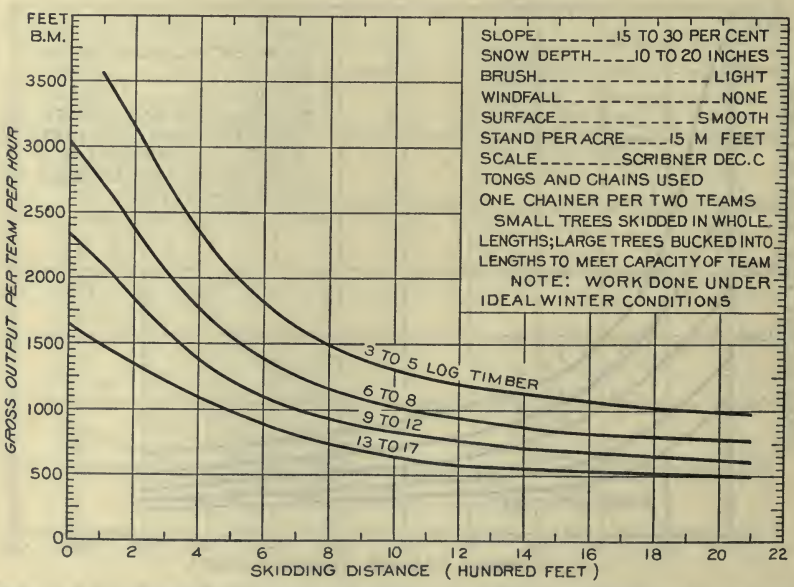

FIGURE 23.—Horse-skidding output, in ponderosa pine type, moderate slope. Day labor, winter work. The work was done under ideal winter conditions. Basis: 258 M feet, 509 trips. Data collected January and February

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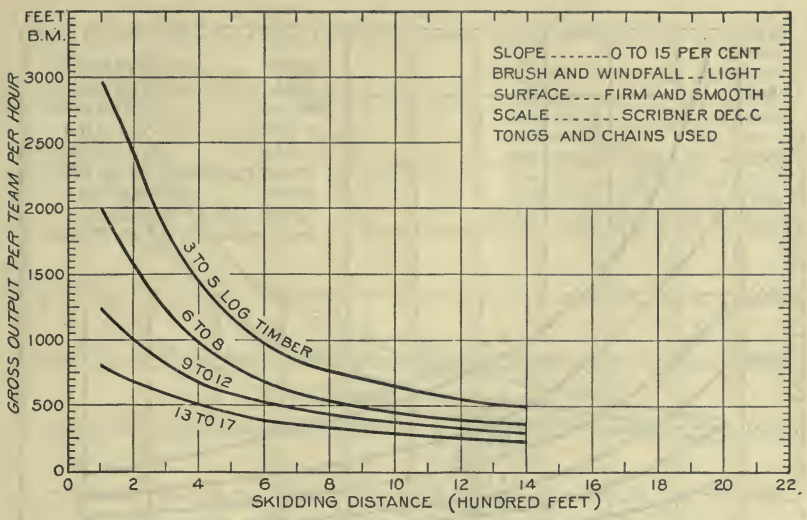

FIGURE 24.—Horse-skidding output, in larch-Douglas fir type, little slope. Day labor, summer work. Basis: 167 M feet, 1,100 trips. Data collected September, 1920

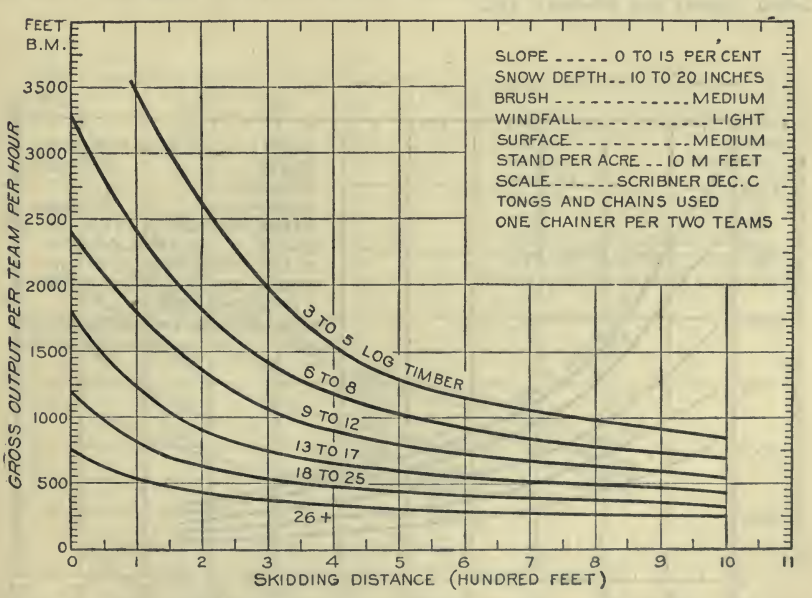

FIGURE 25.—Horse-skidding output, in larch-Douglas fir type, little slope. Day labor, winter work under ideal operating conditions in 1921 and average in 1922. Basis: 1,204 M feet, 9,689 trips. Data collected January and February, 1921 and 1922

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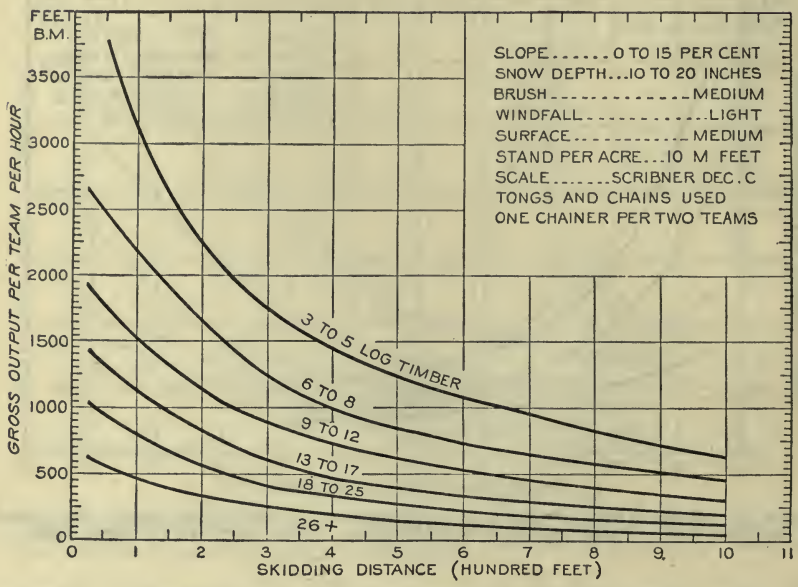

FIGURE 26.—Horse-skidding output, in larch-Douglas fir type, little slope, uphill. Day labor, winter work under ideal conditions. Basis: 192 M feet, 1,666 logs. Data collected January and February, 1922

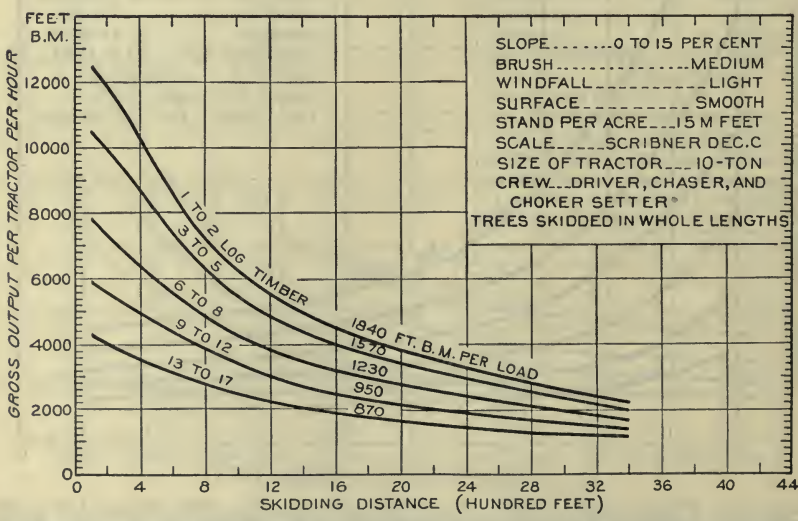

FIGURE 27.—Tractor-skidding output, in ponderosa pine type, little slope. Day labor. Summer work. Basis: 764 M feet, 534 trips. Data collected 1921 and 1922

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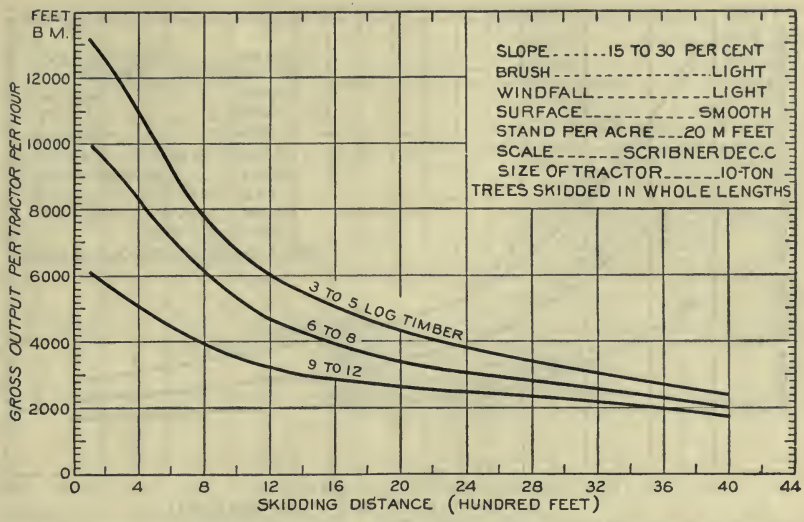

FIGURE 28.—Tractor-skidding output, in ponderosa pine type, moderate slope. Day labor. Summer work. Basis: 860 M feet, 363 trips. Data collected September and October, 1921

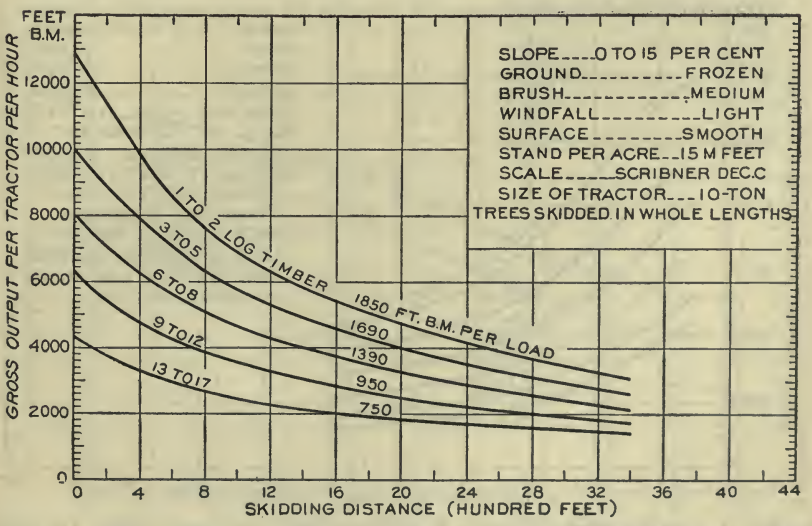

FIGURE 29.—Tractor-skidding output, in ponderosa pine type, little slope. Day labor. Winter work. Basis: 1,635 M feet, 1,074 trips. Data collected January and February, 1923

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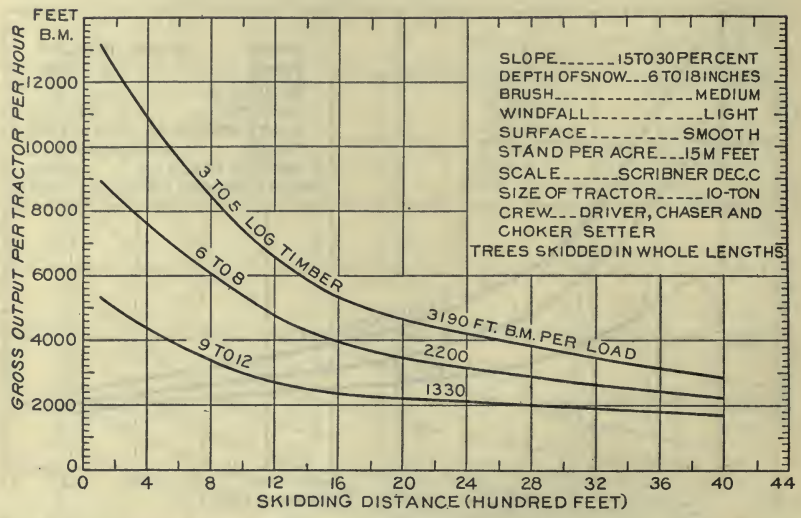

FIGURE 30.—Tractor-skidding output, in ponderosa pine type, moderate slope. Day labor. Winter work. Basis: 782 M feet, 290 trips. Data collected February and March, 1923

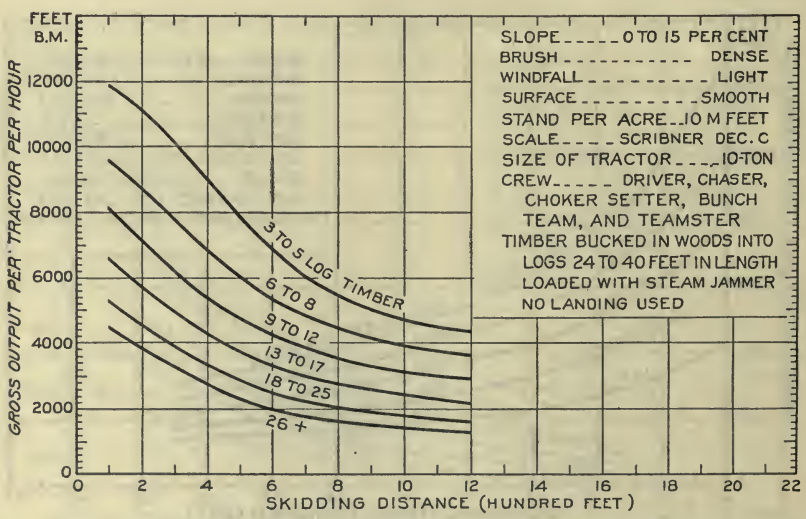

FIGURE 31.—Tractor-skidding output, in ponderosa pine type, little slope. Day labor. Summer work. Basis: 392 M feet, 529 trips. Data collected August and September, 1921.

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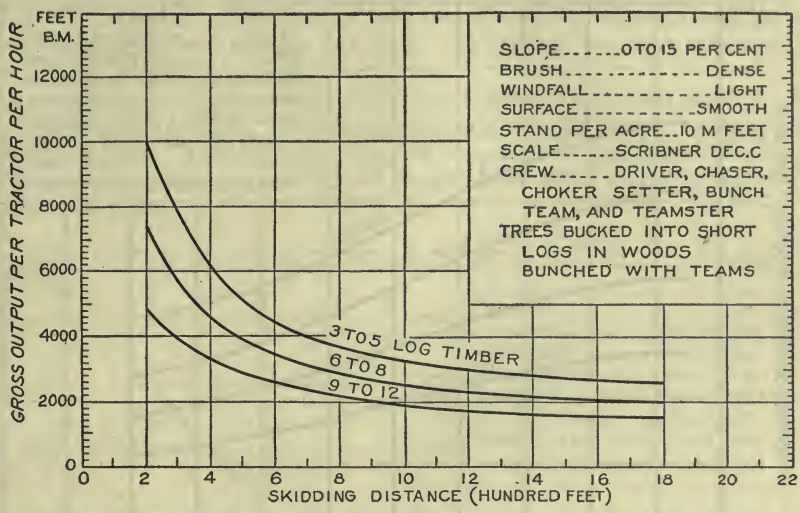

FIGURE 32.—Tractor-skidding output, in ponderosa pine type, little slope, uphill. Day labor. Basis: 230 M feet, 219 trips. Data collected November, 1921

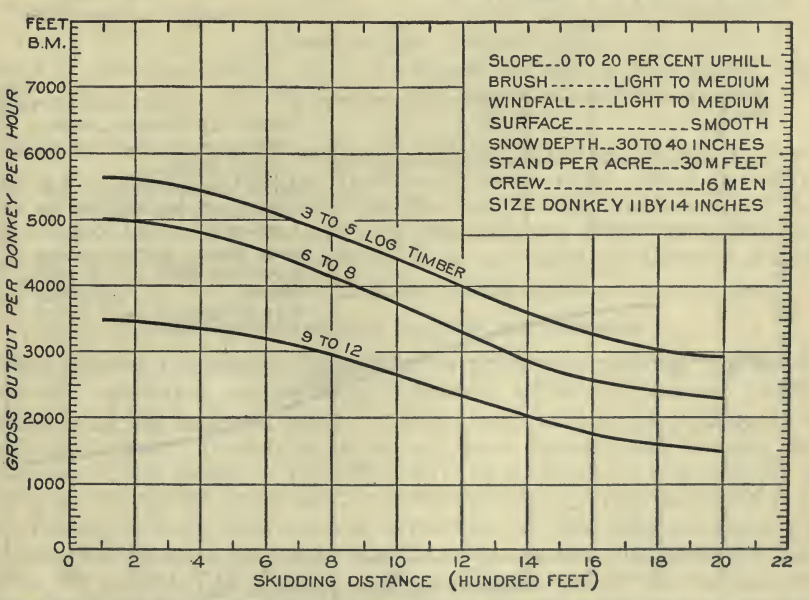

FIGURE 33.—Donkey-skidding (ground-line) output, in western white pine type, little to fair slope, uphill. Contract labor, winter work. Basis: 264 M feet, 128 trips. Data collected January and February, 1921

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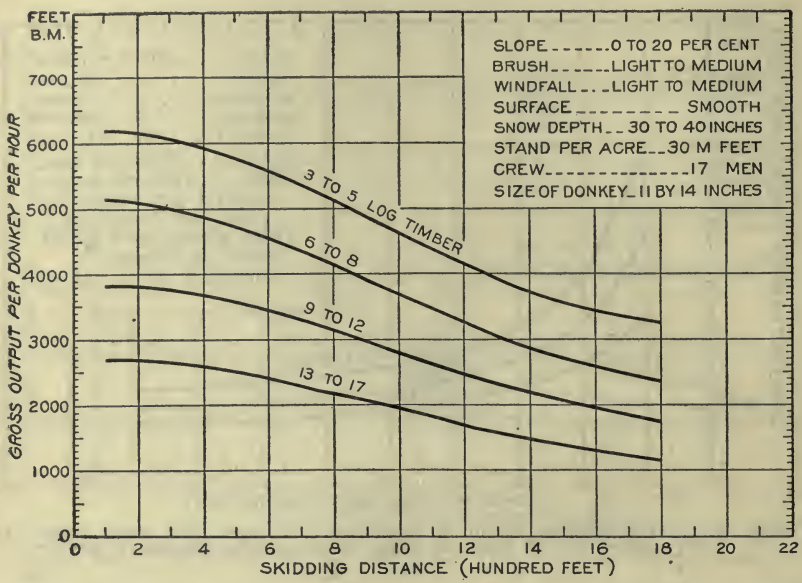

FIGURE 34.—Donkey-skidding (ground-line) output, in western white pine type, little to fair slope, downhill. Contract labor, winter work. Basis: 435 M feet, 284 trips. Data collected January and February, 1921

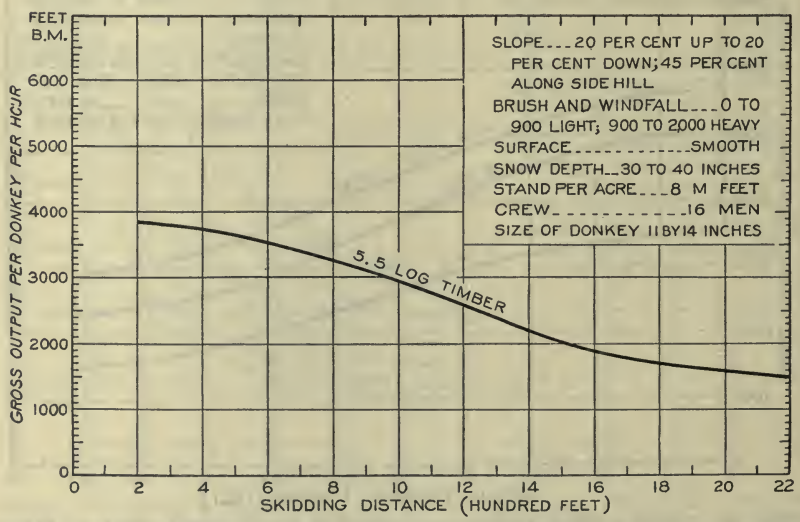

FIGURE 35.—Donkey-skidding (ground-line) output, in western white pine type, easy slope up, and down, also along steep side hill. Contract labor, winter work. Basis: 74 M feet, 45 trips. Data collected January and February, 1920

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The unit organization for ground-line donkey skidding includes, besides the engine crew, choker setters, and whistle punk, the landing saw crews and the loading crew. Sixteen men compose the ordinary crew. The timber is skidded in tree lengths and bucked into short or double-length logs at the landing. Skidding by this method is usually on a contract basis.

In big-wheel skidding the unit crew consists of 5 men with 2 sets of wheels and 8 horses. The 5 men include 2 teamsters, 2 loaders, and a landing man. Individual loads are bunched in the wheel roads by independent crews consisting of team, teamster, and a chainer or cant-hook man.

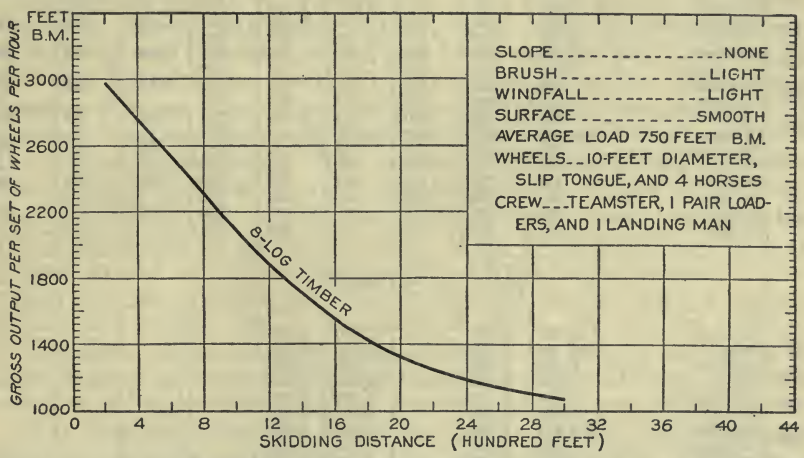

FIGURE 36.—Big-wheel-skidding output, in ponderosa pine type, on level ground. Day labor, summer work. Average time per trip required for loading, unloading, and delays, 9.8 minutes

For each of the several methods studied the output data have been segregated by such natural factors as forest type, stand per acre, size of timber, slope, surface, windfall and brush, and season of the year. Pay basis (day or contract), the make-up of the crew, and the amount of footage upon which the data are based are likewise stated in the legend of each graph or on the graph itself.

EFFECT OF NATURAL FACTORS ON SKIDDING

The size of the timber, the distance from the landing, the slope, and the operating season very definitely affect the output in all methods of log transportation. Some result in a larger, others in a smaller, output. A change in one of these factors may modify the influence of the others. The effect of such reactions is important. A thorough study of each set of skidding data is recommended. A brief analysis here, however, of a number of the different skidding graphs will be made to emphasize the effect of the different factors upon the output. In order to help in the discussion the output per effective hour has been read from a full set each of horse and tractor skidding graphs and is presented in Table 3.

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TABLE 3.—*Skidding output per team per effective hour (gross scale), by degree of slope and size of timber, ponderosa pine, work on day basis*

HORSE SKIDDING [1]

Skidding distance (feet)	Operating season	Slope 0–15 per cent			Slope 15–30 per cent			Slope 30–50 per cent		
		3–5 logs per M	9–12 logs per M	18–25 logs per M	3–5 logs per M	9–12 logs per M	18–25 logs per M	3–5 logs per M	9–12 logs per M	18–25 logs per M
		Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
100	Summer	2,790	1,525	910	3,510	1,800	800	3,040	1,615	690
	Winter	3,250	1,585	815	3,165	1,590	875			
200	Summer	2,200	1,275	785	2,865	1,470	700	2,750	1,340	600
	Winter	2,265	1,325	635	2,865	1,360	780			
400	Summer	1,400	900	565	1,910	1,000	520	1,925	930	445
	Winter	1,450	940	410	2,290	975	590			
600	Summer	1,010	670	400	1,350	720	390	1,390	690	335
	Winter	1,125	700	330	1,775	750	450			
800	Summer	800	525	290	1,040	560	300	1,100	585	280
	Winter	965	585	310	1,375	615	370			
1,000	Summer	665	430	220	845	480	260	965	520	260
	Winter	860	520	280	1,090	550	325			
1,200	Summer	575	370	175	730	425	250	885	470	240
	Winter	775	470	260	960	515	300			
1,600	Summer	410	270	125	600	360	250	785	430	220
	Winter	655	375	200	790	440	230			
1,800	Summer	350	225	115	565	330	250	750	410	210
	Winter	600	320	175	735	400	200			
TRACTOR SKIDDING [2]										
200	Summer	10,025	5,625		12,550	5,775				
	Winter	8,900	5,400		12,350	4,975				
400	Summer	8,750	5,000		11,000	5,075				
	Winter	7,875	4,725		10,850	4,350				
800	Summer	6,350	3,875		7,900	3,950				
	Winter	6,300	3,825		8,375	3,350				
1,200	Summer	4,875	3,050		6,075	3,250				
	Winter	5,275	3,300		6,550	2,700				
1,600	Summer	4,000	2,500		5,000	2,875				
	Winter	4,600	2,850		5,300	2,350				
2,000	Summer	3,400	2,150		4,350	2,650				
	Winter	4,000	2,500		4,650	2,175				
2,400	Summer	2,900	1,850		3,825	2,475				
	Winter	3,525	2,200		4,200	2,075				
3,000	Summer	2,350	1,575		3,200	2,200				
	Winter	2,950	1,875		3,625	1,925				

[1] From figs. 18, 19, 20, 21, and 22.
[2] From figs. 27, 28, 29, and 30.

SIZE OF TIMBER

The effect of the size of the timber upon output is evident in every set of skidding data; size exerts a real influence upon this phase of the logging cost. It is often the case that up to a certain limit just so many pieces, irrespective of size, can be handled per day. The following example will show the direct effect of size of timber upon skidding output:

Summer skidding with horses in the ponderosa pine type on 0 to 15 per cent slopes shows the output (Table 3, column 3, data from Figure 18) in 3 to 5 log per thousand timber skidded a distance of 100 feet to be three times as much as in 18 to 25 log timber. The reason is obvious. Let it be supposed that the team can handle but one of the large logs efficiently per trip. The average log in the 3 to 5 log run will scale approximately 250 board feet. To get the same scale per trip in the small 18 to 25 log timber, 5 logs would have to be bunched and chained or dogged together. Not much, if any, more time would be needed to hook on to a large log than to one of the

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small ones; the hooking-on time may therefore be said to be five times as great for small logs as for large. The 5-log trail would obviously represent a larger bulk than the 1-log trail, but it also represents a considerably greater weight. Owing to their greater percentage of sapwood, small logs weigh more per board or cubic foot than do large ones. Green western white pine logs, running 3 to 7 to the thousand, for instance, weigh only 6,000 pounds per thousand feet, as compared with 7,500 pounds for 8 to 15 log timber. However, it is bulk rather than weight that limits the scale of each load. The trip time from the woods to the landing should if anything favor the bigger timber.

In general, therefore, a smaller output as the size of the material decreases may be attributed to the greater amount of time required to make up and unhook the load and to the smaller board-foot volume that can be taken as the bulk of the load increases. The greatest relative difference in output will naturally occur where bulk is the greatest limiting factor in transportation, as with donkey, tractor, and big-wheel skidding. The smallest difference exists in methods where either the tractive or supporting power, rather than bulk, is the limiting factor, as with autotruck, wagon, sleigh, or dray haul, and horse skidding on the ground. With the tractor, and to a still greater extent with the donkey engine, a limit in the number of pieces which can be skidded per load is reached in the smaller material before the weight has an appreciable effect. A greater difference is therefore found in most cases between the output for small and large timber in tractor skidding than in horse skidding. The same relation exists between donkey skidding and tractor skidding.

It is apparent from the foregoing discussion that skidding output decreases rapidly as the size of the timber decreases. The cost per thousand for small timber is, therefore, much greater than that for large timber when skidding is carried on under the same conditions and by the same method. This is common knowledge and in itself is of value to the operator only in figuring the difference in cost per thousand of skidding different-size timber. Such information is, however, necessary in making appraisals, estimating job costs, and setting the price for contract work. Furthermore, this decrease in output of smaller timber is greater in donkey and tractor skidding than in horse skidding. More advantage, therefore, is gained by the use of the first two methods in the larger timber only. This in an important finding, for it enables the operator or logging engineer to select the method and equipment that will assure the most economical operation for a given size of timber.

SKIDDING DISTANCE

As the actual distance over which the logs or trees must be moved from stump to landing increases, the output, of course, decreases. This is to be noted in every method of transportation discussed subsequently. It may be logically assumed that it takes the same amount of time to make up a load or trail in the woods and unhook it at the landing at a distance 100 feet back as, say, 1,600 feet back, since the scale or the number of the logs in the load is not usually reduced as the distance from the landing increases. The output must then vary in almost direct proportion to the time it takes to

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move the load between the stump and the landing. The variation is greatest, however, in horse skidding, for the animals must be rested at increasingly frequent intervals as the distance over which the load must be hauled increases. To illustrate, the horse-skidding output per team per hour in 3 to 5 log timber (Table 3) when the landing is 200 feet away is 5.37 times the output when it is 1,600 feet away; with tractors under the same conditions the output is but 2.51 times as much.

On level ground the difference in output between different sizes of material varies to a considerable degree according to the distance that the material is moved. The greatest advantage of handling large logs rather than small logs is found in the shorter skidding or hauling distances. As the distances increases, this difference decreases. A thorough understanding of the effect upon output of distance alone and of distance in combination with the other factors is important. Distance, unlike size of timber and percentage of slope, can be changed to advantage by the proper spacing of minor transportation improvements. It should be noted that on level ground the effect of distance in decreasing output is more marked in large than in small timber. That is to say, the already relatively lower output in skidding small logs, evident over short hauls, does not decrease with distance in the same proportion that the output of large logs decreases.

SLOPE

The difference in output between large logs and small logs that is evident on level ground increases considerably with increase in slope, in varying degree according to the method of skidding. With donkey skidding, autotruck or sleigh hauling, and donkey or tractor trailing in chutes, transporting logs on slopes has but little advantage over transportation on nearly level ground. In fact, anything over a very moderate slope causes a reduction in output for some of these methods, since more time may be required to return empty and no increase in speed of travel or size of load may result from having slope with the traffic. This would be particularly true with small material. On the other hand, in some of the largest timber in this region a moderate slope is of some advantage under the methods just mentioned.

Slope causes the greatest differences in output of various sizes with such methods as horse or tractor skidding and horse trailing. The table of outputs (Table 3) shows, with but one exception, that the output in 3 to 5 log per thousand timber is greater on 15 to 30 per cent slopes than on 0 to 15 per cent slopes, for both horses and tractors, at all distances and during both operating seasons. The same is true in 9 to 12 log timber when skidded with horses, but in tractor skidding in the winter a greater output in this size timber is obtained on the gentle slopes than on the steeper slopes. In very small timber the influence which slope has upon output is varied to a considerable degree by the distance over which the logs must be hauled.

On slopes of 45 to 60 per cent, horses skid, per trip, about the same number of logs, except in large timber. The output ratio between sizes is here almost directly in proportion to the difference in

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scale between two average logs of these sizes, particularly for the shorter distances. For the longer distances a greater difference exists between the outputs of large and small timber than on level ground. Thus it may be seen that slope favors large material at all distances but particularly at the greater distances. The advantage is greater also where horses are used for skidding. The number of logs which may be horse skidded per trip on a 45 to 60 per cent slope is usually limited only by the number of trail dogs which the team can take back up the hill.

After a certain percentage of slope is reached, the ratio of output between different-sized timber remains practically constant. This is the percentage of slope at which the most favorable operation starts. It comes earliest under skidding methods where tonnage is a factor, as in hauling by autotruck; next under methods in which slope is of no material advantage, as in donkey skidding; third, in tractor skidding or horse trailing in chutes, which are most effective over slopes of 20 to 30 per cent; and last in horse skidding over slopes of about 45 to 60 per cent. All such ideal slope conditions are for summer weather.

In summing up the effects of slope it may be said that since slope favors large timber at all distances but particularly at the greater distances, the intervals between secondary transportation routes in large timber may thus be greater on steep slopes than on level ground.

OPERATING SEASON

The relation between skidding output and the various natural factors has so far been considered mainly as it prevails in average summer weather. On frozen ground and snow, these relationships change to a very marked degree. Frozen ground covered with snow favors output most on level ground, in large timber, and with long hauls. These are the conditions under which tractive power counts most. Thus horse skidding, being the most limited by lack of power, would have relatively the greatest increase in output in the winter season. This is clearly illustrated later in Table 6.

Winter work on level ground requires on an average about the same tractive power as summer work on 15 to 30 per cent slopes. The advantage offered by winter work diminishes continually as size of timber or distance decreases and as slope increases. A point in the combination of these other factors is finally reached beyond which winter conditions not only prove to be a disadvantage but make the cost of the work prohibitive.

Constant fluctuations in weather conditions result in a good deal of variation in output from day to day. Changing depth of snow is one of the principal causes. Output data based on different depths of snow can neither be obtained nor applied. An average of the various depths under which the work is commonly done must therefore be considered.

Until snow exceeds a depth of 18 or 20 inches, it does not perceptibly cut down skidding output, provided the trees have been felled on top of the snow. Beyond this depth, especially if the snow is packed or crusted, more or less time is lost in breaking trails

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and choking logs. The proportion of time lost in these operations is in inverse ratio to the skidding distance and size of timber. Additional time required for setting chokers is approximately the same for each piece, irrespective of size—the fewer logs per thousand feet the less time per thousand is lost in setting chokers. Also, the shorter the trip the greater the proportion of the trip time used in choking and in breaking a trail through unbroken snow. Usually accumulation is gradual; snow seldom falls in such quantities during one night as to affect appreciably a going operation. Breaking through the snow on each trip from one log to the next is practically the only inconvenience caused by a cover of 2 feet.

Briefly, in winter on frozen ground and snow, a greater proportional skidding output is obtained in large timber and with long hauls. Advantage should be taken of seasonal conditions. Level areas of large timber at greatest distance from improved transportation can be set aside for winter work. A material saving may thus be realized both in moving logs from stump to landing and in the construction of improvements. Since a comparatively longer skidding distance is practical in winter, such improvements as chutes and railroad spurs can in many cases be dispensed with by skidding certain areas in winter rather than in summer.

HOW TO COMPUTE SKIDDING COSTS

Output data for skidding are easily and accurately applied. Their use in determining the cost of skidding on a particular logging unit requires the following steps:

(1) Calculate the average skidding distance for each component part of the unit. This calculation must take into consideration slope, distance between skidways, direct surface distance from tree to skidway as compared with the actual surface distance followed in skidding, and uniformity of timber distribution over the area with relation to distance from the landing points. As a rule, skidways are built at intervals of 200 to 400 feet along the transportation route. The actual skidding distance from point to point ranges from 15 to 30 per cent more than the direct distance with an average of about 20 per cent. Consequently the average skidding distance for an area having a uniform distribution of stand may be obtained by taking 60 per cent of the greatest average direct distance from stump to route of transportation. The biggest trees and largest yields per acre are usually on the lower slopes and bottoms. Such unequal distribution of the timber stand affects the average skidding distance. The following example is given to illustrate the method used to compensate for this influence.

To find the average skidding distance for a maximum skidding distance of 1,200 feet, with 60 per cent of the timber lying within the first 600 feet, first take 60 per cent of 600 feet, or 360 feet, for the 600-foot strip. Within the second part of the strip, also 600 feet wide, the average skidding distance would be 60 per cent of 600 feet, as in the first part, or 360. But these logs must also traverse the first or closest half of the area, which has a direct width of 600 feet, or an actual average skidding distance of 720 feet (20 per cent more than the direct distance). Adding the 720 feet necessary to traverse

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the first part and the 360 feet for the second gives a total average skidding distance within the second part of 1,080 feet.

If 60 per cent of the timber must be skidded 360 feet and 40 per cent 1,080 feet, then: $(360 \times 0.60) + (1{,}080 \times 0.40) = 648$ feet, the actual average skidding distance for the area.

(2) Compute the average number of logs per thousand for each subdivision or skidding unit. Where trees or double-length logs are handled in tractor or donkey operations, the logs per thousand should be determined in terms of the number of 16-foot logs per thousand, irrespective of the length into which the timber may be bucked.

(3) Determine for each skidding unit the gross output per hour for the average skidding distance from the proper logs-per-thousand curve which best fits the specific operating conditions. Reference to Table 2 will assist in this selection.

(4) Obtain the gross daily output by multiplying the gross output per hour by the number of effective hours per day. Effective hours per day are the measure of time actually put in on the job each day, depending on the distance to work and the standard length of the working day. On the basis of an 8-hour day, effective time usually ranges from 7 to 7¾ hours.

(5) Obtain the net daily output by reducing the above figure by the estimated percentage of defect.

(6) Find the net cost of skidding per thousand feet by dividing the daily cost of the unit skidding crew by the net daily output. Skidding-crew cost records are illustrated by Tables 14, 15, 18, and 19.

The following examples are given to illustrate the proper use of the graphs:

EXAMPLE A

To find the cost per thousand of skidding with horses with a specified size and species of timber and conditions of operation:

In a stand of ponderosa pine running 15,000 feet board measure per acre, the timber averages between six and eight logs per thousand and is estimated as 5 per cent defective. Brush and windfall over the area are light, but the slope is about 40 per cent. The average skidding distance is 600 feet. It is planned to log the area in the summer. Work will be done on a day basis of pay, and the men will be expected to put in eight hours per day on the job. The area will be swamped before skidding.

To find the skidding cost per thousand proceed as follows:

According to the horse-skidding graph in Figure 20, selected as best fitting the given stand and operating conditions, 6 to 8 log timber shows the gross output per team per effective hour over an average distance of 600 feet to be 1,000 board feet, making the gross daily output per team 8,000 feet board measure. Reducing this gross daily output by the estimated 5 per cent defect yields a net daily output of 7,600 feet board measure. To find the net cost of skidding per thousand divide the daily cost of the skidding crew, which in this case includes a team and teamster and half time of a dogger (Table 18) by the net daily output (7,600 feet board measure). The result is a net skidding cost of $1.27 per thousand.

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EXAMPLE B

To find the cost per thousand of skidding with tractors with specified size and species of timber and conditions of operation:

In a stand of ponderosa pine running 15,000 feet board measure to the acre, in moderately heavy brush and on moderately level ground (the slope in no place being more than 15 per cent) large timber averaging four logs per thousand, with 15 per cent defect, is to be skidded in tree lengths by a unit crew of tractor and driver, chokerman, and swamper, putting in nine hours a day on the job. The logging will be done during the summer. The average skidding distance is 1,600 feet.

To find the skidding cost per thousand, consult the tractor-skidding graph in Figure 27 (selected as best fitting the specific stand and operating conditions). Here, 4-log timber has a gross output per tractor per effective hour of 4,000 feet board measure, or 36,000 feet for a 9-hour day. Reducing this gross daily output by the estimated 15 per cent defect yields 30,600 feet board measure as the net daily output.

Crew costs are as follows:

	Cost per hour
Tractor and driver (Table 19)	$3.77
Choker man (Table 16); average rate $4.15 per 8-hour day	.52
Swamper (Table 16); average rate $3.40 per 8-hour day	.42
Total	4.71

Crew cost for a 9-hour day thus equals $42.39. This cost divided by the net daily output of 30,600 feet board measure gives a net cost of skidding per thousand of $1.39.

ANALYSIS OF LOADING AND UNLOADING OUTPUT DATA

Graphs for loading and unloading output are summarized in Table 4. Figure 37 shows two curves representing sleigh-loading output per crew per hour in feet board measure, gross-scale, by log-per-thousand sizes, of two different crews—one a 5-man crew with horse jammer, the other a 4-man crew using a crosshaul. Figure 38 gives the output per crew per hour of loading auto trucks, and also the unloading output. In both Figures 37 and 38 the loading output is based on the actual loading time. Loading-output data in order to be of practical and permanent value must be based only upon actual loading time. The organization of the crew, the method of handling employed, and the type of loader used must be recorded with each set of data.

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TABLE 4.—*Index to loading and unloading graphs and transportation other than skidding*

Figure No.	Method	Organization and equipment	Size timber	Forest type	Slope	Labor	Season	Weather conditions
			Logs per thousand		*Per cent*			
	LOADING AND UNLOADING							
37	Loading sleighs	Horse jammer; 5 men, crosshaul, 4 men.	3–22	Western white pine-larch-fir.		Day	Winter	
38	Loading and unloading autotrucks.	End horse-jammer loading, 5-man man crew, 2 cant-hook men unloading.	2–20			do	Summer	
	TRANSPORTATION							
39	Draying and skidding, horses	(1)	10	Ponderosa pine	0	Day	Winter	(1).
40	Dray haul	3 drays; loading crew, 3 men and teams.	3–12	Western white pine	0–15	do	do	Weather and snow conditions ideal.
41	Chute trailing, teams	Chutes; 3 to 9 teams depending on distance.	1–12	Ponderosa pine	0–10	do	Summer	Average.
42	do	do	6–25	do	0–15	do	Winter	Temperature below freezing; conditions ideal.
43	Chute trailing, tractors	Chute, 10-ton tractor	1–12	do	0–10	do	Summer	Average.
44	Sleigh haul	4 horses per sled; 4 and 5 sleds hauling.	10	Larch-Douglas fir	[2] 0–15	do	Winter	Weather and snow conditions ideal.
45	do	2 horses per sled; roads poorly constructed.	3–17	do	[2] 0–12	do	do	Temperature slightly below freezing; too warm for good sleighing.
46	Autotruck haul	5-ton truck, no trailer; plank road; 3 trucks hauling.	3–12	Western white pine	[2] 0–6	do	Summer	Average.
47	do	7½-ton truck, no trailer	9.5	Ponderosa pine	(3)	do	Winter	Good winter weather.
48	do	7½-ton truck, no trailer; road wet and soft.	3–17	do	0–6	do	Summer	

[1] See chart.
[2] Downhill.
[3] 5 per cent uphill for 600 feet then 0–15 per cent down.

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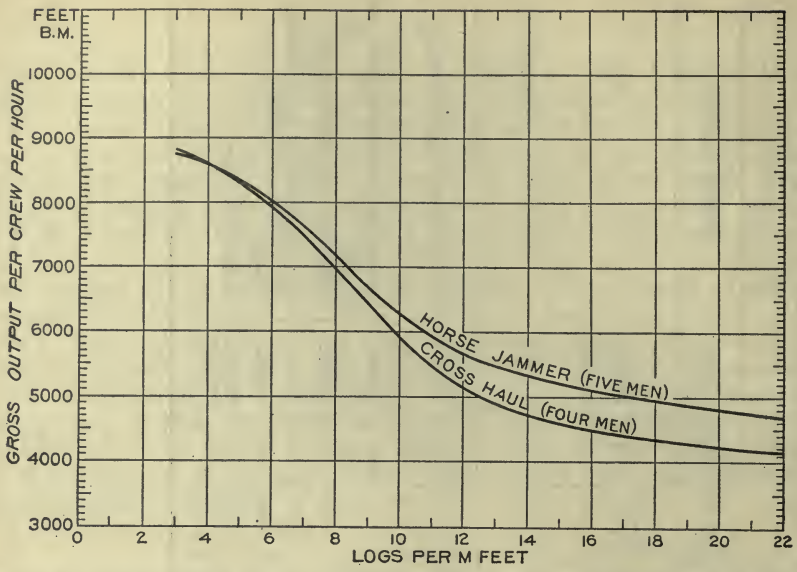

FIGURE 37.—Sleigh-loading output, with horse jammer and 5-man crew, and crosshaul and 4-man crew, both day labor. The curves represent output of actual loading time, including only such lost time as is incidental and properly chargeable to loading, putting the two methods on a comparative basis. Time lost in waiting for logs or sleds is not included but must be considered separately in accordance with the nature of any specific organization or job. Basis: Horse jammer, 222 M feet board measure, western white pine; crosshaul, 160 M feet board measure, larch-Douglas fir. Scale, Scribner decimal C. Data collected January–February, 1921

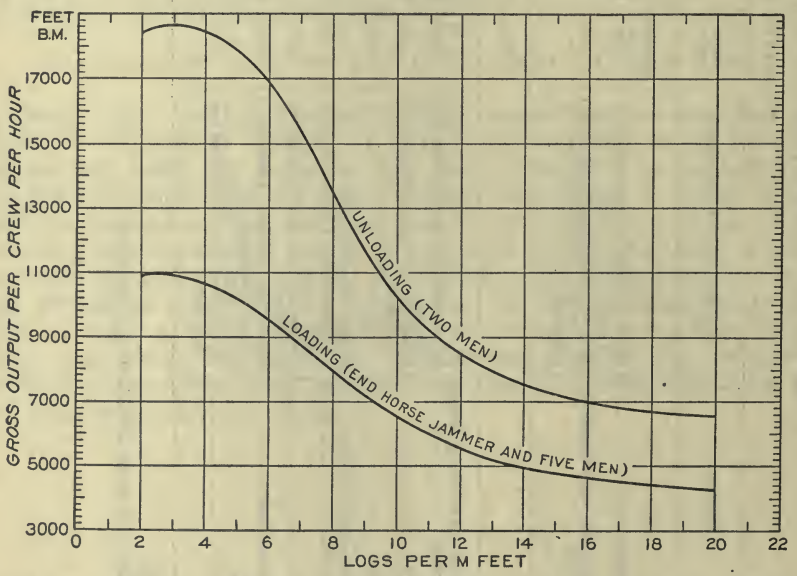

FIGURE 38.—Autotrucks loading and unloading output, with day labor. Loading-crew teams and teamster, top loader, 2 hookers, 1 taildown man; unloading crew, 2 canthook men. Only actual loading time and that lost which is properly chargeable to loading is included. Time lost waiting for logs or trucks is not included. Basis: 765 M feet board measure, 292 loads. Average per load, 2,620 feet board measure. Scale, Scribner decimal C. Data collected May, 1923

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EFFECT OF VARIOUS FACTORS UPON OUTPUT

In the loading of logs upon sleighs, auto trucks, and railroad cars the organization of the crew, the method employed, and the equipment in use will largely determine the efficiency of the crew and are therefore of first importance. The location and character of the skidways in relation to the crosshaul, horse jammer, or power loader are important factors in increasing output. Any difference in output per unit of time as between two identical loading crews handling the same sized logs under the same conditions and methods and using the same type of loader will depend upon the time lost in waiting for logs or trucks or sleighs. The cost of loading in this region is perhaps affected more by such lost time than by any other factor. Maximum output per hour or per day can be obtained only by having available at all times enough logs to load and sufficient empty trucks or sleighs upon which to load them.

The output per effective hour based on actual loading time for a given loading crew will be influenced appreciably only by the size of the timber; length and form of the logs may, however, affect it slightly. A considerable percentage of very long or very short logs mixed with the usual run of 12, 14, and 16 foot logs will tend to lessen the output because of the greater difficulty of handling such logs. The same is true where the run includes a number of rough, knotty, much-tapered, or crooked logs.

Though it takes less time to load small logs than large ones, the output is not at all in proportion to the scale. That is, a log scaling 50 board feet can not be loaded in half the time that it takes to load a log containing 100 board feet. According to the loading curve in Figure 38, the approximate time necessary to load a 20-per thousand log is 43 seconds. The curve shows that it takes 55 seconds to load one 10-per-thousand log. This means that 1,000 feet board measure of the larger logs can be loaded in approximately two-thirds of the time required for the smaller logs.

The three loading curves in Figures 37 and 38 all clearly emphasize this effect of size of timber upon output. All three curves show a gradual increase in output from the smallest logs to the 12-log-per-thousand size group. Logs up to 12 per thousand may be classed as small. Where each log is loaded separately with hooks the output is necessarily low. This output may be increased by loading several logs together in looped chains. Beyond the 12-log-per-thousand size group, the output per crew per effective hour increases rapidly as the size of the timber increases, up to the largest logs. Medium to fairly large logs seem to be best suited for loading with horse jammer or crosshaul. The output increases more slowly as the timber increases in size from five logs per thousand. With power loaders, rapid increase in output would continue to a much larger log size.

The curves in Figure 37 compare the output obtained by two different-sized loading crews using different methods and equipment. The output obtained by the 4-man crew loading logs with a crosshaul averages 575 feet board measure less per effective hour for logs running between 22 and 12 logs per thousand than that obtained by the 5-man crew using a horse jammer. As the timber increases in size beyond the 12-log-per-thousand group the differ-

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ence in output obtained by the two crews diminishes until 5-log-per-thousand timber is reached, where the output per crew is the same. It is evident from the curves that in loading logs smaller than five logs per thousand on sleighs, a greater output per effective hour based on actual loading time can be obtained from a 5-man crew with a horse jammer than from a 4-man crew loading with a crosshaul.

The loading output per effective hour for 4-man crews in 16, 10, and 5 log per thousand timber is, respectively, 4,500, 5,900, and 8,325 feet board measure, as compared with 5,100, 6,300, and 8,325 feet for 5-man crews. Just what factors or group of factors are responsible for this increased output by the 5-man crew in the smaller sizes of timber was not definitely determined by these studies. The additional man on the crew, the arrangement of the loading works, or the efficiency of the crew and loader may all influence the output. It is evident, however, that the size of the timber exerts a considerable influence on the output. If this were not so, an equal increase in output over that of the 4-man crew would be obtained by the 5-man crew, regardless of the size of the timber.

The output per effective hour of a 2-man crew unloading auto-trucks (fig. 38) is influenced principally by such factors as size of timber, location of sleigh or truck landing in reference to pond, river, or yard into which the logs are to be unloaded, and the relation of actual unloading time to the time lost in waiting for loads to arrive. Proper facilities for unloading should be set up. The time lost by unloading crews in waiting for loaded trucks or sleds can be regulated by limiting the number of such crews until the time lost is negligible. The size of the timber will, therefore, exert the greatest influence upon output.

It will be noted that there is a very rapid increase in output as the size of the timber increases, particularly in the size groups between 10 and 5 logs per thousand. This shows that the larger and heavier the logs the easier it is to unload them. Once the key log of the load is set free by the cant-hook men, the remainder of the logs above the bottom tier usually roll off of their own weight, if the landings are properly constructed. Small logs which fit more tightly on the load often have to be rolled off singly. There is a limit, of course, to the size and weight of logs that can be handled advantageously by the unloading crew, especially if the heavy logs are loaded on the bottom of the truck or sled. This is shown by the fact that the output for 2-log-per-thousand timber dropped 200 feet board measure per crew per hour below that for logs running 3 logs per thousand.

HOW TO COMPUTE LOADING AND UNLOADING COSTS

The use of the output data to determine the cost per thousand of loading and unloading logs requires the following steps:

(1) Compute the average number of logs per thousand that are to be loaded or unloaded.

(2) Determine the gross output per hour for this computed size of timber from the graph which fits the specific operating conditions, methods, and equipment.

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(3) Obtain the net output per hour of loading or unloading by reducing the above figure by the estimated percentage of defect.

(4) Find the net cost of loading or unloading per thousand by dividing the hourly cost of the loading or unloading crew by the net hourly output.

EXAMPLE A

Compare the cost per thousand of loading sleighs with a 4-man crew using a crosshaul and a 5-man crew using an end horse-jammer:

The timber runs 10 logs per thousand and is estimated to be 7 per cent defective. The job is so organized that there is practically no time lost in waiting for either logs or sleighs.

According to the horse-jammer curve of Figure 37, the gross output of 10-log timber per effective hour of a 5-man crew using the end horse-jammer is 6,300 feet board measure. The crosshaul curve shows the output per effective hour of the 4-man crew using a crosshaul to be 5,900 feet board measure gross scale. These figures are then reduced by 7 per cent for defects to 5,859 and 5,487 feet board measure net hourly output, respectively. Average hourly cost per unit 5-man crew (from Table 19) is $2.83. If this is divided by the net hourly output for the horse-jammer crew (5,859 feet) the result is 48 cents per thousand, the cost of loading. The hourly cost of a 4-man loading crew (one less cant-hook man than the 5-man crew) is $2.37, which divided by the net hourly output of 5,487 feet equals 43 cents per thousand, cost of loading.

EXAMPLE B

To find the cost per thousand of unloading autotrucks with a crew of two men employed on a day basis:

The timber runs 10 logs to the thousand and is 7 per cent defective. On the unloading curve (fig. 38) the gross output per crew per effective hour for 10-log timber is 10,250 feet, and the net hourly output (reduced for defect) is 9,532 feet board measure. Table 15 gives the average wage of a cant-hook man as $3.70 for an 8-hour day. The crew cost would be $7.40 a day or 92 cents an hour. This sum divided by the net hourly output equals 9.6 cents per thousand for unloading autotrucks.

ANALYSIS OF DATA FOR TRANSPORTATION OTHER THAN SKIDDING

In other methods of log transportation such as trailing in chutes, and dray, sleigh, and autotruck haul the general procedure is so similar both in obtaining and in applying the data that these methods can well be discussed together. The results of the studies are given in Figures 39 to 48.

Team and teamster constitute the unit crew for dray hauling and ordinarily for trailing in chutes with horses. In tractor trailing in chutes a 10-ton machine and a driver constitute a unit. The unit organization for sleigh hauling is a teamster and two or four horses. In autotruck hauling there is the driver with a truck of 5 or 7½ ton capacity. Details of organization are given on each graph. Output is based on logs-per-thousand groups, corresponding in prac-

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tically all cases to the grouping used in skidding. The unit scale per load is also shown in most cases.

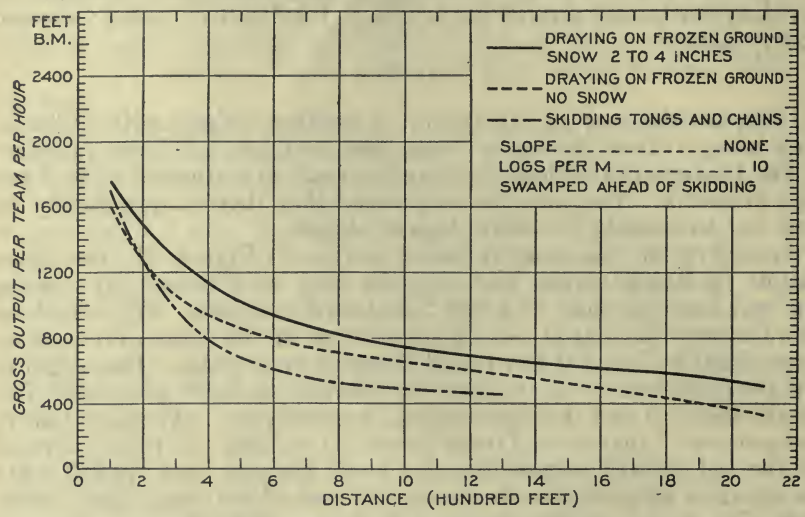

FIGURE 39.—Draying and skidding output in ponderosa pine type, winter work, day labor. Basis: 280 crew days, 1,530 M feet board measure

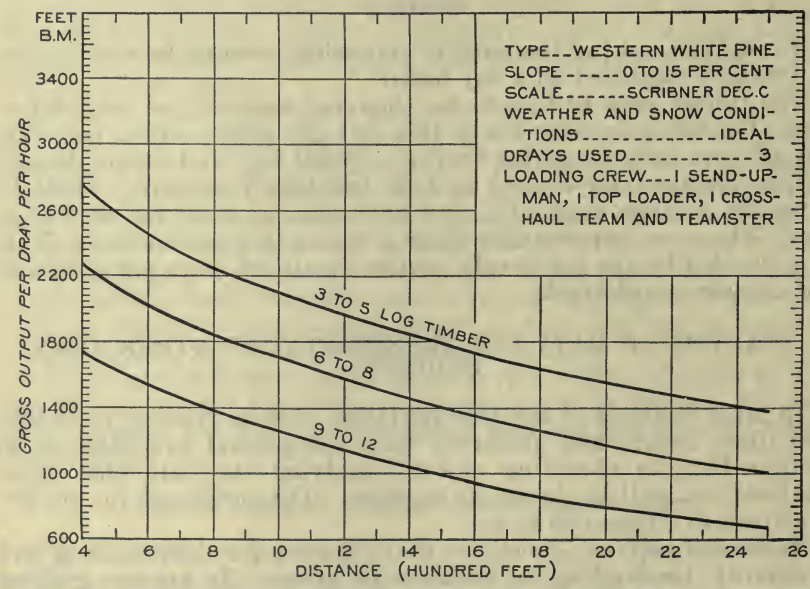

FIGURE 40.—Dray-haul output, in western white pine, winter work, day labor. Owing to ideal weather and snow, the output is greater than could be expected under average conditions. This output is identical with that obtained by a gyppo doing his own loading and tail-down work in a ponderosa pine type. All other conditions were similar. Basis: 840 M feet board measure, 1,103 trips. Data collected January–February, 1922

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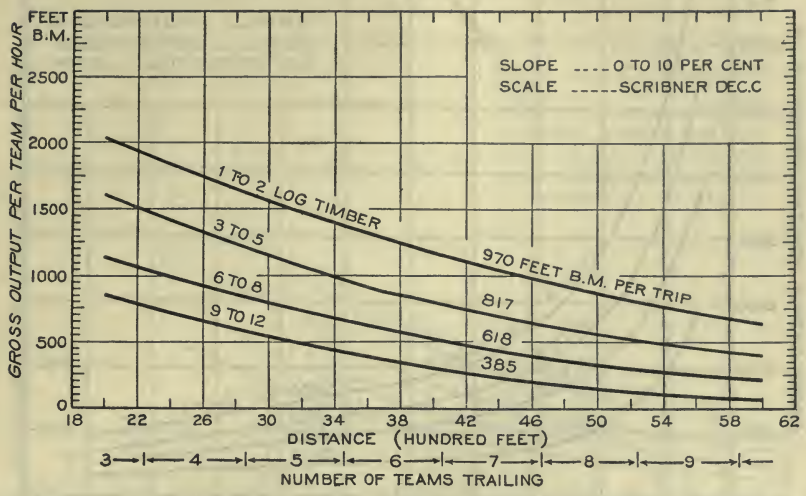

FIGURE 41.—Chute trailing output with teams, in ponderosa pine type. Summer work, day labor. Number of teams includes jig team. The chute was well constructed with easy curves. Basis: 146 M feet board measure, 186 trips

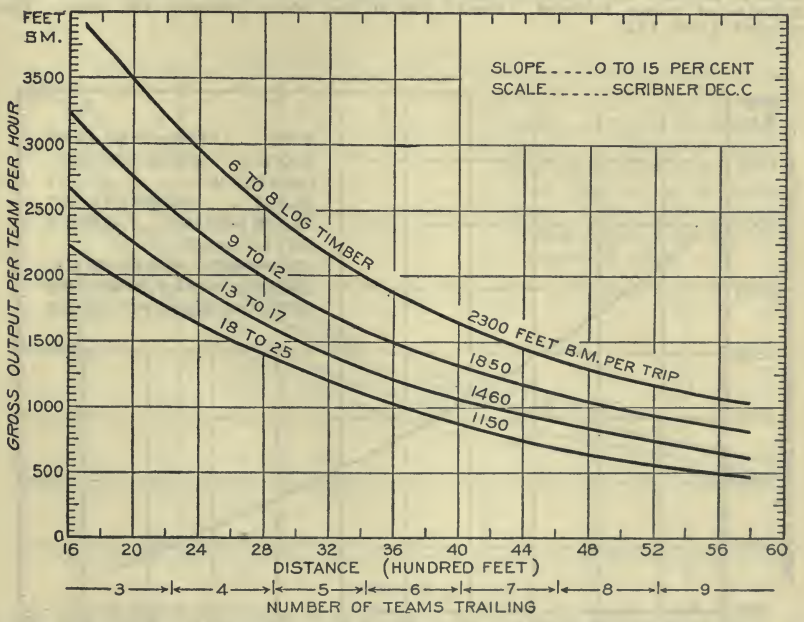

FIGURE 42.—Chute-trailing output with teams, in ponderosa pine type. Winter work. Day labor. Low temperature made chuting conditions ideal. Basis: 1,265 feet board measure, 705 trips. Data collected December, 1921

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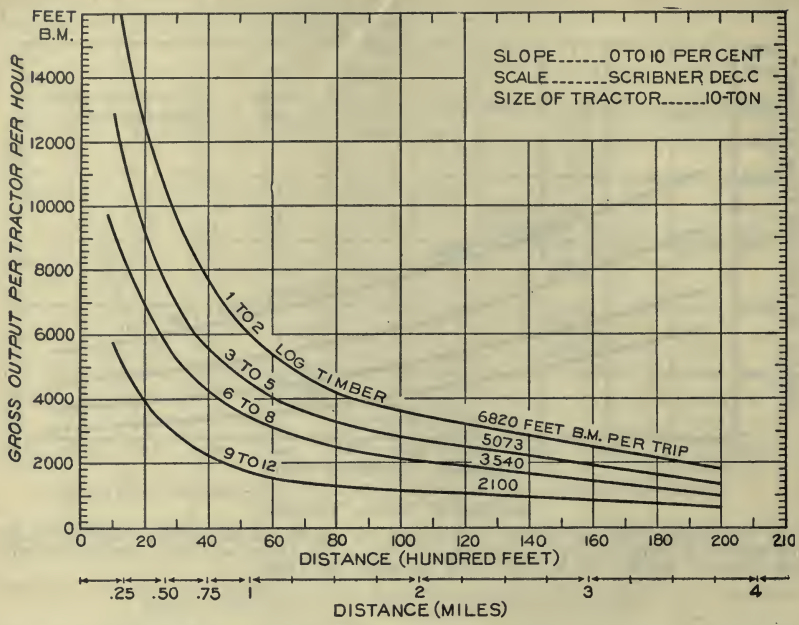

FIGURE 43.—Chute-trailing output with tractor, in ponderosa pine type. Summer work. Day labor. Chute was well constructed, with easy curves. Two teams making up trails at skidway and two discharging at landing. Only distance covered by tractor, exclusive of teams, included. Basis: 506 M feet board measure, 105 trips. Data collected June, 1923

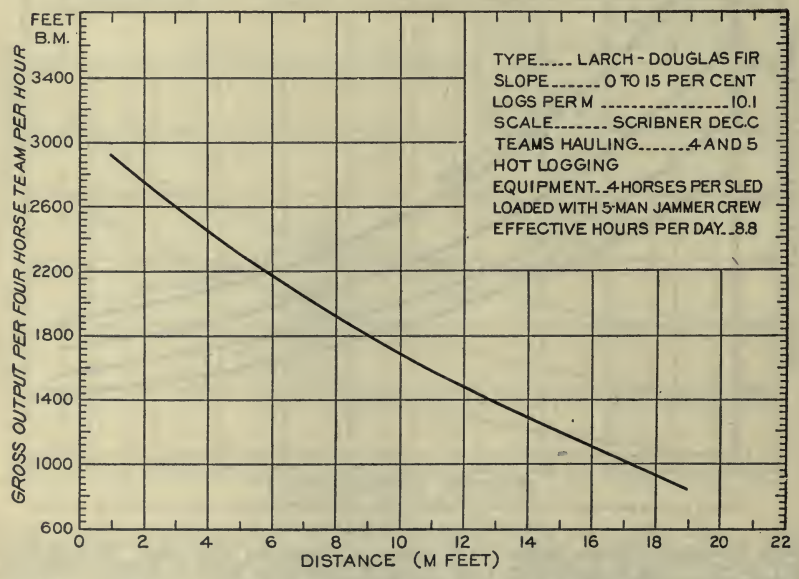

FIGURE 44.—Sleigh-haul output, with four horses per sled; weather and snow conditions very favorable, with temperature continually below freezing. Basis: 1,996 M feet board measure, 317 trips. Data collected January–February, 1922

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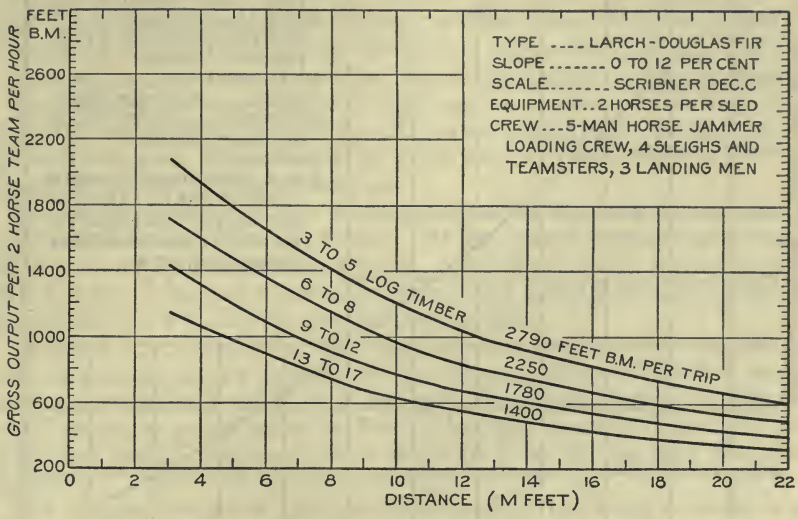

FIGURE 45.—Sleigh-haul output, with two horses per sled. Roads were poorly constructed, temperature slightly below freezing—too warm for good sleighing. Basis: 150 M feet board measure, 67 trips. Data collected January–February, 1921

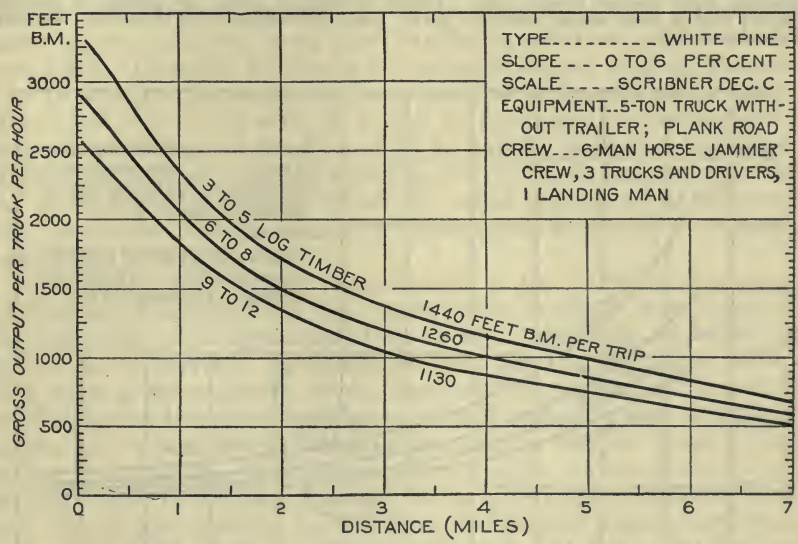

FIGURE 46.—Output for autotruck haul with 5-ton truck without trailer, plank road. Size of load limited to about 1,500 feet by condition of road. Basis: 104 M feet board measure, 549 logs, 88 trips. Data collected July, 1922

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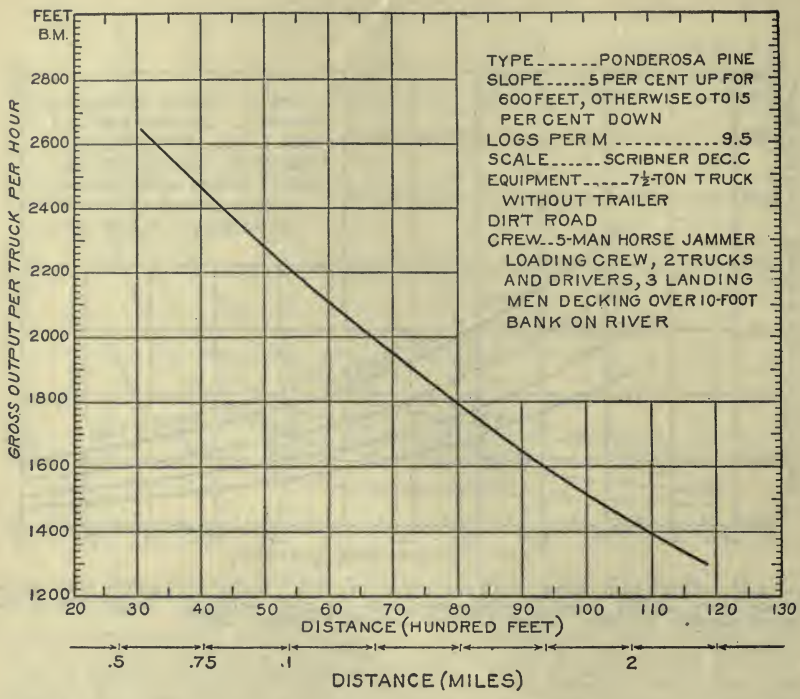

FIGURE 47.—Output for autotruck haul with 7½-ton truck without trailer, dirt road, winter work. Practically no grading or swamping required for roads. Temperature below freezing with ground frozen solid. Trucks average 3 miles per gallon of gasoline. Basis: 669 M feet board measure, 6,413 logs, 330 trips. Data collected January–February, 1922

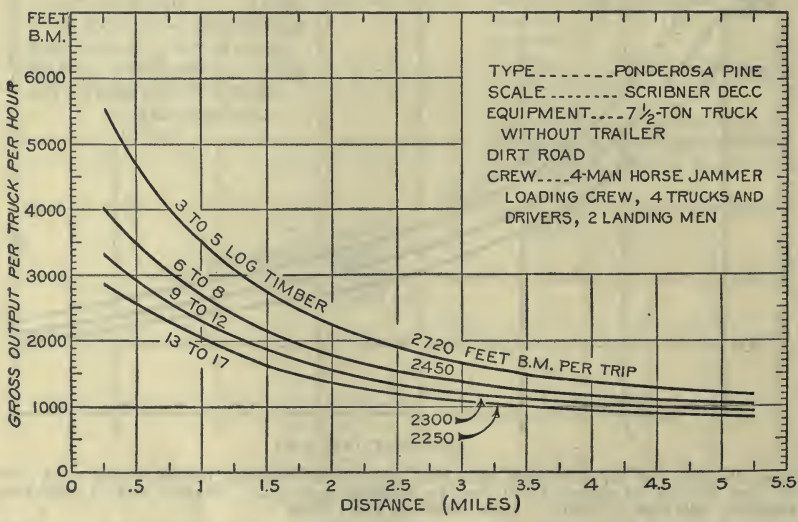

FIGURE 48.—Output for autotruck haul with 7½-ton truck without trailer, dirt road, wet and soft, summer work. Basis: 668 M feet, board measure, 262 trips. Data collected May, 1923

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EFFECT OF NATURAL FACTORS UPON OUTPUT

The natural factors—size of timber, distance, slope, and operating seasons—which affect skidding output influence the output in all other methods of log transportation; and the basic facts or principles of logging brought out in the discussion of skidding apply likewise to trailing in chutes and hauling on drays, sleighs, and autotrucks.

The output obtained by trailing logs in chutes or hauling them on drays, autotrucks, or sleighs decreases rapidly as the size of the timber decreases. The following examples will be sufficient to show the effect of size on timber output:

The output per dray per hour obtained in hauling a distance of 1,000 feet is found (fig. 40) to be 2,100 feet board measure gross scale for 3 to 5 log per thousand timber, 1,700 feet board measure gross scale for 6 to 8 log per thousand timber, and 1,250 feet board measure gross scale for 9 to 12 log per thousand timber.

Trailing in chutes (fig. 43) registers an output per tractor per hour in trailing logs a distance of 1 mile as follows: 4,400 feet board measure gross scale in 3 to 5 log per thousand timber; 3,350 feet board measure gross scale in 6 to 8 log per thousand timber; and 1,750 feet board measure gross scale in 9 to 12 log per thousand timber.

The output per truck per hour obtained in trucking a distance of 4 miles is found (fig. 46) to be 1,150 feet board measure gross scale in 3 to 5 log per thousand timber; 1,000 feet board measure gross scale in 6 to 8 log per thousand timber; and 875 feet board measure gross scale in 9 to 12 log per thousand timber.

As in skidding, it is practically impossible, with the supporting and tractive power available, to haul or trail the same scale per load in small logs as in the very large timber. Often only just so many pieces, irrespective of size, can be handled on each load or in each trail. In order to obtain the same scale per load in the small 9 to 12 log per thousand timber as in the average load or trail of the larger 3 to 5 log size, it would be necessary, according to the data given in Figures 40, 43, and 46, to handle the following number of logs: Dray haul, 8 of the small logs to 3 of the larger logs; trailing in chutes with tractor, 53 of the small logs to 20 of the larger logs; and autotruck haul, nearly three times as many of the small logs as of the larger ones.

In hauling, bulk rather than weight is the limiting factor, and the limited capacity of the dray, autotruck, or sleigh would preclude the handling of enough small logs to equal the scale of larger logs that could be carried. However, as shown in the discussion of skidding, even if the capacity of the transporting equipment were ample to handle the increased number of small logs, a point would soon be reached where the greater weight of the smaller timber would be too great for the tractive power available. This would be particularly true in trailing logs in chutes with horses; ample room is available in any chute to handle a trail of logs of almost any length, but there is a limit to the weight of logs in the trail that the team can start. Even with tractor trailing, small logs are more costly to transport.

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Log chutes are usually designed to handle the larger logs of the run. Small logs do not ride in the chute so well and are more apt to jump out, shove past the log in front, or buckle from pressure behind. For these reasons a trail composed of a number of small logs mixed with some very large ones, or of too many small logs, is difficult and costly to handle.

In hauling, distance also greatly increases the loss in output of small as compared with large timber. The gross output per hour for all sizes of timber decreases as the distance it must be transported increases; regardless of the scale per load, fewer trips are made per hour or per day. With fewer loads per day added to a lower scale per load, the decrease in output per hour for small timber is more rapid for each increase in distance than it is for large timber. As an example, the gross output per hour for 9 to 12 log timber dray hauled (fig. 40) a distance of 2,000 feet is less than half the output per hour that can be obtained when draying logs of the same size a distance of but 500 feet. In 3 to 5 logs per thousand timber the gross output per hour at 2,000 feet is 60 per cent of that at 500 feet.

Slope is an important factor in all transportation. The method and equipment to be used in transporting logs are dependent upon the percentage of slope. The slopes practicable for trailing in chutes and hauling with drays, autotrucks, and sleighs are gentler than those for skidding. Slope causes the greatest difference in output of various sizes of timber in draying and horse trailing, favoring large material at all distances. However, when a certain percentage of slope is reached the relation in output between different-sized timber remains practically constant. This point comes earliest in those methods, such as hauling by autotruck, where a definitely limited capacity makes tonnage a factor.

In certain types of transportation the season of the year and weather conditions are of particular importance. Though sleigh hauling demands a snow or ice surface, constant fluctuations in weather conditions result in a good deal of variation in output from day to day. Ideal weather and snow depth will allow a greater output in dray hauling than average conditions. Figures 41 and 42 illustrate effectively the output variation due to change in operating seasons and weather conditions. The trailing recorded in Figure 41 was done in summer; that in Figue 42 was done in January and February with the temperature continually below freezing, making chuting conditions ideal. In both cases the chutes were well constructed, and other conditions were practically the same. The output for summer chuting per team per hour in 6 to 8 log per thousand timber was 1,150 feet board measure gross scale trailed a distance of 2,000 feet, 800 feet board measure at 3,000 feet, 525 feet board measure at 4,000 feet, and 350 feet board measure for the 5,000-foot distance. Output per team per hour in winter chuting for the same size of timber and over the same distances reaches 3,500 feet board measure, 2,325 feet board measure, 1,650 feet board measure, and 1,225 feet board measure, respectively.

Where transportation is effected by wheeled vehicles, seasonal influences are generally negligible. In some cases the roadbed is improved in winter, in others it becomes more difficult.

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HOW TO COMPUTE TRANSPORTATION COST

There is so little difference in the steps necessary in the specific application of the hauling data under the various methods of hauling that one set of instructions will suffice.

(1) Calculate the average draying, chuting, sleigh-haul, or autotruck-haul distance for the specific chance. In the examination of the logging area the method of minor log transportation will have been decided upon and the length and location of dray, sleigh, and autotruck roads and chutes tentatively determined.

(2) Compute the average number of logs per thousand.

(3) Determine the gross output per hour for the average distance hauled or chuted from the proper logs per thousand curve on the graph which fits the specific method under consideration. Reference to Table 4 will assist in this selection.

(4) Obtain gross daily output by multiplying the gross output per hour by the number of effective hours per day.

(5) Obtain the net daily output by reducing the above-mentioned figure by the estimated percentage of defect.

(6) Find the net cost of hauling or chuting per thousand feet by dividing the daily cost of the unit crew by the net daily output. Types of unit-cost records applicable to those branches of the operation are shown in Tables 14, 15, 16, and 21.

EXAMPLE A

To find the cost per thousand of dray hauling in the white pine type:

This chance (in the white pine type) is considered ideal for dray haul. Weather and snowfall in this particular district can usually be depended upon to afford good conditions for the use of drays. The slope is slight, averaging between 5 and 10 per cent. The average hauling distance is estimated at 1,000 feet. The logs will run 9 to 12 per thousand feet board measure. The timber is estimated as being 10 per cent defective. Eight effective hours on the job will constitute a day's work.

The cost is then estimated as follows:

The 9 to 12 log per thousand curve in Figure 40 shows the gross output per dray per hour for such timber hauled a distance of 1,000 feet to be 1,260 feet board measure. This makes the gross daily output 10,080 feet board measure, and the net daily output (10 per cent reduction) 9,072 feet board measure.

Average costs per unit crew are as follows:

Cost of team and teamster (Table 13) per effective day	$8.00
One-third of the average cost per effective day of woods-loading crew capable of loading three drays (top loader, $4.15; send-up man, $3.70; crosshaul team and teamster, $8)	5.28
Daily cost of unit crew	13.28

This amount divided by the net daily output gives $1.46 as the cost per thousand of dray haul.

EXAMPLE B

To find the cost per thousand of trailing ponderosa pine logs in a chute with teams:

Chuting is to be done in the summer, in well-constructed chutes with easy curves. The average distance over which logs must be

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trailed in the chute is computed as 3,600 feet. The timber will run six to eight logs per thousand and is estimated at being 5 per cent defective. It is planned to have the men put in eight effective hours on the job.

The 6 to 8 log per thousand curve in Figure 41 gives the gross output per team per hour for 6 to 8 log timber trailed an average distance of 3,600 feet as 625 feet board measure. The graph shows that the number of teams used in trailing this distance would be six. This number includes the jig team. For the 8-hour day the gross daily output is then 5,000 feet board measure, and the net daily output (5 per cent reduction) 4,750 feet board measure.

Average costs per unit crew are as follows:

Cost of team and teamster (Table 13, 1929)	$7.30
One-fourth cost of jig team and teamster ($7.30 per day)	1.82
One-fifth cost of two men greasing chutes ($3.30 per day each)	1.32
Daily cost of unit crew	10.44

This amount divided by the net daily output=$2.20, the cost per thousand of trailing in chutes with teams, exclusive of the cost of chute grease.

EXAMPLE C

To find the cost per thousand of autotruck haul:

The distance is 3 miles over a good dirt road, the grade (6 per cent or less) being all downhill. Four 7½-ton trucks without trailers will be used on the job. It is estimated that a 5-man loading crew with a horse jammer will keep the four trucks going Two landing men will be needed: The timber is ponderosa pine running six to eight logs per thousand and 3½ per cent defective. Eight effective hours on the job will constitute a day's work.

The six to eight log per thousand curve in Figure 48 gives the daily output per truck per hour for a distance of 3 miles as 1,400 feet board measure, or 11,200 for an 8-hour day. The net daily output is then 10,808 feet. The unit cost per effective day of autotruck-haul crew, as given in Table 20, is $24.70. Dividing this by 10,808 feet board measure (net daily output) gives $2.29 as the cost per thousand autotruck haul.

ANALYSIS OF SWAMPING AND SLASH-DISPOSAL DATA

The output in swamping and slash disposal is much more difficult to classify than that in any other branch of logging work.

The brush itself can not be measured by methods that would be practicable in application. One thousand feet board measure of timber cut is used as the unit of measuring performance, but it does not express accurately the amount of brush handled. The quantity of brush or slash per thousand feet of timber cut varies greatly, not only among different species but even within the same species. This difference results from variations in undergrowth, stand density, tree heights, and many other factors which can not be classified in output studies. Accordingly these phases of logging must be treated on a different and more general basis.

One man is taken as a unit in swamping and slash disposal, or in fact on any job in which each laborer works independently. In

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contract horse skidding a working unit includes teamster and swamper, the teamster often assisting in swamping. Under day-work, swampers are not included in the crew, as swamping is usually done in advance of the skidding. Under present practice in tractor skidding one swamper may be included to work with the crew. Output and cost are influenced by the same factors in both slash disposal and swamping, and generally in the same manner.

The data contained in Table 5 were obtained from slash-disposal jobs in the white pine type of northern Idaho. Work in all cases was done during the summer season. The information on which the table is based is insufficient to justify more than very general conclusions. As previously indicated, this is probably all that could be expected from any amount of data on these operations.

EFFECT OF NATURAL FACTORS UPON OUTPUT

The natural factors which are chiefly instrumental in causing a wide variation in swamping and slash-disposal output are size and height of timber, stand per acre, composition of species, breakage, cull, and defect, utilization of tops, timber left uncut, and season of the year.

Size of timber undoubtedly is one of the more important single influences upon output in both jobs. Compare a 4-log tree, 18 inches in diameter, scaling 280 board feet, with a 6-log tree 40 inches in diameter which contains 2,800 board feet. The former has probably fully one-third as much slash in the top as the latter. This means that one-third as much work in limbing and slash disposal is charged against the 280 feet of volume in one case as is charged against ten times that volume in the second.

Height of timber is also an important factor. Tall timber has much less slash per thousand feet. The limbs are smaller and can be handled much more easily than the long limbs from short, scrubby timber.

Stand per acre affects both swamping and slash disposal, but not in the same manner. In a very heavy stand the cost per thousand of swamping may be greater than in a light stand, but usually that of slash disposal is less. The influence of stand per acre is brought out in Table 5, though rather indefinitely, by plot 2, where density is the only condition differing materially from those on the comparable plots. The large output of 1,390 board feet per hour on plot 2 is, in all probability, due to denseness of stand. A greater percentage of the brush must be handled by the swampers than in light stands. Often it is necessary to fell trees crosswise and on top of one another, which makes swamping more difficult than when all timber lies flat on the surface. On the other hand, there is less brush for disposal per thousand feet of timber cut, and a smaller percentage must be moved in piling. A larger proportion than usual must be piled by the swampers to clear the skid trails, a feature of the work that sometimes represents 60 to 80 per cent of the total cost of swamping. This would be the case in scattered stands of white pine where heavy windfall and dense clumps of hemlock and white fir saplings occur. In such stands slash-disposal costs would also be increased, but not to the same extent as swamping costs.

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TABLE 5.—*Slash disposal output, western white pine type; summer season*[1]

Plot No.	Area	Density of windfall	Slope	Stand per acre	Western white pine			White fir and Douglas fir			Cedar—hemlock			Total volume	Time required	Output per effective hour
					Total volume	Size	Height	Total volume	Size	Height	Total volume	Size	Height			
	Acres		*Per cent*	*M ft.*	*M ft. b. m.*	*Logs per M*	*Logs per tree*	*M ft. b. m.*	*Logs per M*	*Logs per tree*	*M ft. b. m.*	*Logs per M*	*Logs per tree*	*M ft. b. m.*	*Hours*	*Ft. b. m.*
PILING AND BURNING																
1	19.8	Light	45	31.6	433	14.0	4.3	186.0	8.7	4.1	7.0	15.0	3.5	626.0	690.0	907
2	13.2	Medium	45	40.9	276	13.0	4.4	246.0	8.2	4.4	18.0	12.3	3.2	540.0	388.5	1,390
3	10.5	do	45	25.9	162	10.2	5.0	95.0	8.1	5.4	15.3	12.0	3.3	272.3	225.0	1,210
4	38.3	Heavy	10	34.4	1,319	8.5	5.6							1,319.0	2,093.0	630
5	10.0	Medium	45	21.2	125	12.7	5.0	69.0	6.3	5.1	18.0	8.4	4.2	212.0	297.5	713
6	26.8	do	30	34.2	711	7.0	7.3	69.0	13.0	4.0	136.0	9.0	4.5	916.0	1,283.0	714
PROGRESSIVE BURNING																
7	17.4	Medium	5	40.5	371	4.5	8.0	50.0	12.0	4.2	284.5	9.0	4.0	705.5	1,224.0	576
8	49.5	Light	5	36.7	1,201	5.5	8.0	87.1	13.0	4.0	530.1	9.0	5.0	1,818.2	4,350.0	418

[1] Density of undergrowth light on all plots.

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Windfall has little effect on slash disposal except where windfall is so heavy that it becomes difficult to find clear spaces where the slash may be piled. This necessitates carrying the slash and accordingly reduces the output. This effect is illustrated by plot 4 in Table 5, where windfall was exceptionally heavy. The output of 630 board feet per effective hour on this plot is much lower than that on all other plots where slash was first piled and then burned (Nos. 1, 2, 3, 5, and 6), although other factors on this plot would tend to produce an average or above-average output.

Composition of stand has an important influence on the output or cost of swamping and slash disposal. Pure to almost pure stands of western white pine can be handled much more cheaply than stands containing considerable cedar, white fir, hemlock, and spruce. The same is true of a pure ponderosa pine type, as compared with ponderosa pine in mixture with considerable Douglas fir. Species such as hemlock, white fir, and Douglas fir, which are quite tolerant of shade and capable of good growth under their own shade and that of other species, do not prune their trunks of their lower branches but retain them in a green growing state throughout most of the life of the tree. Western white pine, on the other hand, can not endure much shade. Its shaded branches die off rapidly, and the tree usually cleans itself for a considerable distance above the ground. Outside of such generalities, it is impossible to determine definitely the effect that the various percentages of different species in the many different combinations that occur in this region may have on output.

Breakage occurs largely in the tops and therefore reduces the cost of swamping but increases that of slash disposal. Work which would otherwise have been done in swamping is added to the other operation. Cull and defect increase the cost per thousand of both swamping and slash disposal by reducing the net scale against which total cost is chargeable.

Poor utilization of tops has an effect similar to breakage. With close utilization swampers must trim more brush per thousand feet handled and slash-disposal men correspondingly less.

The quantity of timber left uncut is an important factor, but one which is difficult to classify or to appraise with regard to its effect on output. Standing trees often increase the cost per thousand feet of slash disposal for the timber removed. This cost, however, may still be much lower than where all species are cut to the smallest merchantable size. As an example, in a ponderosa pine type containing 30 per cent Douglas fir the cost per thousand feet of slash disposal is increased if the fir is left standing, since a considerable proportion of the Douglas fir limbs are knocked off in felling the pine. In order to protect from brush-burning fires the timber left standing after a selection cutting, the slash must be removed from around the bases of these trees and piled at a safe distance from them. This additional labor adds slightly to the cost of slash disposal.

Snow greatly increases the cost of swamping when it reaches a depth of more than 1 foot. The cost of slash disposal in the deep snow is prohibitive.

In Table 5 the output under two different methods of slash disposal has been compared. In the progressive method of disposal

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(plots 7 and 8) the brush was burned as piled. In the other method (plots 1 to 6) the brush was first piled and later burned as a separate job. The table shows that under the progressive method the output is only about one-half that of the average for piling alone, in spite of the fact that the progressive method was employed in larger timber where output should be favored. For burning brush previously piled, the output per man averages about 10,000 per hour. Thus it may be seen that little change would occur in the present relative output between the two methods if the output for piling alone were to be reduced by the time spent later in burning the piles.

Steep slopes may become a handicap to the progressive method of slash disposal. The heat and smoke from the fire make piling in close from above very disagreeable. Day laborers in particular will carry the brush along the sidehills or place it on the fire from below rather than work from above. This, of course, increases the cost. In contrast to this, where piling and burning operations are carried on separately the bulk of the brush is thrown downhill without inconvenience to the worker. Progressive burning by contract crews is, however, often the cheapest and most satisfactory method of disposal. One great disadvantage is the shortness of the season in which the slash may be disposed of efficiently by progressive burning.

No further conclusions can be drawn with any degree of certainty. The data presented, however, indicate in a general way what may be accomplished in the white pine type under similar general conditions. They also serve as specific illustrations of some factors influencing output in swamping and slash disposal.

HOW TO COMPUTE SLASH-DISPOSAL COSTS

Use of the output data given in Table 5 is limited to the determination of the cost per thousand feet of slash disposal in the western (Idaho) white pine timber type. It will not be possible to select a plot that coincides in every respect with the specific operation to be studied, but the data presented will serve as a basis upon which to figure average costs. After selecting the plot which most closely approximates the area to be logged, note the output per man per effective hour, as given in board feet, gross log scale. This, multiplied by the number of effective working hours and reduced by the estimated percentage of defect, will give the net daily output. The cost per thousand feet is that found by dividing the labor cost by the net daily output.

The following example will illustrate the method of application.

EXAMPLE

To find the cost per thousand of slash disposal in a heavy western white pine stand:

The timber, which is 50 per cent western white pine, 45 per cent white fir and Douglas fir, and 5 per cent cedar and hemlock, runs 40,000 feet board measure to the acre. The white pine will run 13 logs per thousand, the white fir and Douglas fir 8 logs, and the cedar and hemlock 12 logs. The timber (all species) will average 5 per cent defective. The undergrowth is light, and there is only an average amount of windfall on the ground. Because of the slope,

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which is approximately 45 per cent, the brush will first be piled and later burned. The brush-crew men will be expected to put in eight effective hours on the job.

Plot 2 most closely represents the conditions given. The output per man per effective hour is 1,390 board feet gross scale of brush piled, or 11,120 board feet in gross daily output. Reduction of 5 per cent for defect leaves 10,564 board feet net daily output. The cost per day of swamper or brush piler (Table 18) being $3.40, the cost per thousand of piling brush is $0.322.

For burning brush previously piled, the output per man per hour averages 10,000 feet. This is a good figure for this region. With the labor cost at $3.40 per day this comes to 4 cents per thousand. Total piling and burning cost is thus 36 cents per thousand.

APPLICATION OF OUTPUT DATA TO OPERATING PROBLEMS

Logging-output data can be used to great advantage both in planning and executing logging operations. Such data serve as a basis for a definite and accurate comparison of the relative advantages of the several methods of skidding and minor transportation, for an estimate of the effect of the location of minor improvements upon the cost of these methods, and for the consideration of other phases of the operation between the stump and the landing. Sound decisions on such points make possible the selection of the most economical and suitable system of major transportation. Too often the type of major transportation is considered and adopted without adequate consideration of its effect on the cost from stump to landing. When a detailed analysis of the whole problem has been made, certain characteristics of the area may warrant the adoption of minor improvements and certain methods of sawing and skidding which in themselves are so economical as to justify a means of primary transportation that would otherwise appear unwarranted. Such use of output data could be discussed at great length but can probably best be emphasized by illustrations of the actual application of the data to specific operating problems.

Tables 6 and 7 afford a comparison between skidding with horses and 10-ton track-laying tractors in the ponderosa pine type. There is shown the proper spacing of improvements and the most feasible methods of skidding for different stand, slope, weather, and construction-cost conditions. In all, 16 different operating and stand conditions are covered. For each condition a comparative combined cost per thousand feet of railroad construction and skidding by horses and by tractor is given for the range of distances ordinarily encountered. Beginning with the 0 to 15 per cent slope classification, output and cost are shown for two separate log groups, with two different stand volumes and under both summer and winter conditions. The same comparisons are then presented for a slope classification of 15 to 30 per cent. Similar comparisons may be made from the output charts for many other operating problems upon different slopes, for different sizes of timber, etc., whenever doubt exists as to the most feasible operating method. From such data it is not difficult to determine the most economical methods or combination of methods.

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TABLE 6.—*A comparison of skidding with horses and track-laying tractors, on 0 to 15 per cent slopes, with railroad cost of $2,000 per mile.*

SUMMER SEASON

Average actual skidding distance (feet) [1]	Railroad cost, by stand per acre [2]		Skidding with track-laying tractor [3]								Skidding with horses [3]							
			3 to 5 logs per M		9 to 12 logs per M		Cost including railroad construction [4]				3 to 5 logs per M		9 to 12 logs per M		Cost including railroad construction [4]			
							3 to 5 logs per M		9 to 12 logs per M						3 to 5 logs per M		9 to 12 logs per M	
	10 M	20 M	Output	Cost per M	Output	Cost per M	10 M	20 M	10 M	20 M	Output	Cost per M	Output	Cost per M	10 M	20 M	10 M	20 M
	Dollars	*Dollars*	*Ft.b.m.*	*Dollars*	*Ft.b.m.*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Ft.b.m.*	*Dollars*	*Ft.b.m.*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
60	8.25	4.12	10,700	0.54	6,100	0.94	8.79	4.66	9.19	5.06	2,990	0.40	1,630	0.74	8.65	4.52	8.99	4.86
120	4.12	2.06	10,450	.55	5,880	.97	4.67	2.61	5.09	3.03	2,685	.45	1,485	.81	4.57	2.51	4.93	2.87
180	2.75	1.38	10,100	.57	5,680	1.01	3.32	1.95	3.76	2.39	2,320	.52	1,335	.91	3.27	1.90	3.66	2.29
240	2.06	1.03	9,730	.59	5,550	1.04	2.65	1.62	3.10	2.07	1,990	.61	1,195	1.01	2.67	1.64	3.07	2.04
300	1.65	.82	9,350	.61	5,300	1.08	2.26	1.43	2.73	1.90	1,735	.70	1,075	1.13	2.35	1.52	2.78	1.95
360	1.38	.69	8,950	.64	5,100	1.12	2.02	1.33	2.50	1.81	1,520	.80	965	1.25	2.18	*1.49*	2.63	*1.94*
420	1.18	.59	8,560	.67	4,900	1.17	1.85	1.26	2.35	1.76	1,340	.90	870	1.39	2.08	1.49	2.57	1.98
480	1.03	.52	8,150	.70	4,740	1.21	1.73	1.22	2.24	1.73	1,200	1.01	790	1.53	2.04	1.53	*2.56*	2.05
540	.92	.46	7,770	.74	4,570	1.25	1.66	1.20	2.17	*1.71*	1,090	1.11	725	1.67	2.03	1.57	2.59	2.13
600	.82	.41	7,400	.77	4,400	1.30	1.59	*1.18*	2.12	1.71	1,010	1.20	670	1.81	*2.02*	1.61	2.63	2.22
660	.75	.38	7,060	.81	4,220	1.36	1.56	1.19	2.11	1.74	940	1.29	620	1.95	2.04	1.67	2.70	2.33
720	.69	.34	6,720	.85	4,080	1.40	1.54	1.19	*2.09*	1.74	880	1.37	575	2.10	2.06	1.71	2.79	2.44
780	.63	.32	6,400	.90	3,900	1.47	1.53	1.22	2.10	1.79	825	1.47	540	2.24	2.10	1.79	2.87	2.56
840	.59	.30	6,130	.93	3,770	1.52	*1.52*	1.23	2.11	1.82	780	1.55	510	2.37	2.14	1.85	2.96	2.67
900	.55	.28	5,890	.97	3,610	1.59	1.52	1.25	2.14	1.87	735	1.65	480	2.52	2.20	1.93	3.07	2.80
960	.52	.26	5,630	1.02	3,500	1.64	1.54	1.28	2.16	1.90	700	1.73	450	2.69	2.25	1.99	3.21	2.95
1,020	.48	.24	5,400	1.06	3,370	1.70	1.55	1.30	2.18	1.94	665	1.82	430	2.81	2.30	2.06	3.29	3.05
1,080	.46	.23	5,200	1.10	3,240	1.77	1.56	1.33	2.23	2.00	630	1.92	410	2.95	2.38	2.15	3.41	3.18
1,140	.43	.22	5,030	1.14	3,140	1.82	1.57	1.36	2.25	2.04	600	2.02	390	3.10	2.45	2.24	3.53	3.32
1,200	.41	.20	4,870	1.18	3,040	1.89	1.59	1.38	2.30	2.09	575	2.10	370	3.27	2.51	2.30	3.68	3.47

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60	8.25	4.12	9,740	0.59	5,900	0.97	8.84	4.71	9.22	5.09	3,565	0.34	1,695	0.71	8.59	4.46	8.96	4.83
120	4.12	2.06	9,400	.61	5,650	1.01	4.73	2.67	5.13	3.07	3,040	.40	1,525	.79	4.52	2.46	4.91	2.85
180	2.75	1.38	9,090	.63	5,400	1.06	3.38	2.01	3.81	2.44	2,435	.50	1,370	.88	3.25	1.88	3.63	2.26
240	2.06	1.03	8,780	.65	5,200	1.10	2.71	1.68	3.16	2.13	2,030	.60	1,225	.99	2.66	1.63	3.05	2.02
300	1.65	.82	8,420	.68	5,000	1.15	2.33	1.50	2.80	1.97	1,750	.69	1,100	1.10	2.34	1.51	2.75	1.92
360	1.38	.69	8,100	.71	4,820	1.19	2.09	1.40	2.57	1.88	1,540	.79	995	1.22	2.17	1.48	2.60	*1.91*
420	1.18	.59	7,800	.73	4,660	1.23	1.91	1.32	2.41	1.82	1,395	.87	900	1.34	2.05	*1.46*	2.52	1.93
480	1.03	.52	7,520	.76	4,500	1.27	1.79	1.28	2.30	1.79	1,280	.95	815	1.48	1.98	1.47	*2.51*	2.00
540	.92	.46	7,250	.79	4,380	1.31	1.71	1.25	2.23	1.77	1,195	1.01	750	1.61	1.93	1.47	2.53	2.07
600	.82	.41	7,000	.82	4,250	1.35	1.64	1.23	2.17	*1.76*	1,125	1.08	700	1.73	1.90	1.49	2.55	2.14
660	.75	.38	6,760	.85	4,120	1.39	1.60	1.23	2.14	1.77	1,070	1.13	650	1.86	*1.88*	1.51	2.61	2.24
720	.69	.34	6,540	.88	4,010	1.43	1.57	*1.22*	2.12	1.77	1,015	1.19	620	1.95	1.88	1.53	2.64	2.29
780	.63	.32	6,320	.91	3,900	1.47	1.54	1.23	2.10	1.79	970	1.25	590	2.05	1.88	1.57	2.68	2.37
840	.59	.30	6,140	.93	3,800	1.51	1.52	1.23	2.10	1.81	935	1.29	560	2.16	1.88	1.59	2.75	2.46
900	.55	.28	5,980	.96	3,710	1.54	1.51	1.24	*2.09*	1.82	900	1.34	540	2.24	1.89	1.62	2.79	2.52
960	.52	.26	5,800	.99	3,620	1.58	1.51	1.25	2.10	1.84	870	1.39	525	2.30	1.91	1.65	2.82	2.56
1,020	.49	.24	5,650	1.01	3,550	1.61	*1.49*	1.25	2.09	1.85	845	1.43	510	2.37	1.91	1.67	2.86	2.61
1,080	.46	.23	5,520	1.04	3,480	1.65	1.50	1.27	2.11	1.88	820	1.48	495	2.44	1.94	1.71	2.90	2.67
1,140	.43	.22	5,400	1.06	3,400	1.69	1.49	1.28	2.12	1.91	795	1.52	480	2.52	1.95	1.74	2.95	2.74
1,200	.41	.20	5,280	1.09	3,320	1.73	1.50	1.29	2.14	1.93	775	1.56	470	2.58	1.97	1.76	2.99	2.78

[1] Average actual skidding distance is half the maximum actual distance, or 60 per cent of the maximum direct distance from stump to railroad.

[2] Twice maximum direct skidding distance is taken as distance between spurs since skidding on these slopes will be from both sides of spur. Costs vary directly with area served and stand per acre.

[3] Output (taken from figs. 18, 21, 27, and 29) is per hour at average skidding distance (60 per cent of maximum direct) and costs are per thousand feet board measure. Cost is figured by dividing crew cost by output per effective hour for each distance. Crew costs are figured from cost tables given in appendix.

[4] Figures in italic indicate the actual skidding distance at which all factors combine to produce the lowest total cost.

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TABLE 7.—*A comparison of skidding with horses and track-laying tractors, on 15 to 30 per cent slopes, with railroad cost of $3,000 per mile*

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Average actual skidding distance (feet) [1]	Railroad cost by stand per acre [2]		Skidding with track-laying tractor [3]								Skidding with horses [3]							
			3 to 5 logs per M		9 to 12 logs per M		Cost including railroad construction [4]				3 to 5 logs per M		9 to 12 logs per M		Cost including railroad construction [4]			
							3 to 5 logs per M		9 to 12 logs per M						3 to 5 logs per M		9 to 12 logs per M	
	10 M	20 M	Output	Cost per M	Output	Cost per M	10 M	20 M	10 M	20 M	Output	Cost per M	Output	Cost per M	10 M	20 M	10 M	20 M
60	24.75	12.38	13,400	0.43	6,300	0.91	25.18	12.81	25.66	13.29	3,770	0.32	1,965	0.62	25.07	12.70	25.37	13.00
120	12.38	6.19	13,000	.44	6,080	.94	12.82	6.63	13.32	7.13	3,375	.36	1,740	.70	12.74	6.55	13.08	6.89
180	8.25	4.12	12,640	.45	5,850	.98	8.70	4.57	9.23	5.10	2,975	.41	1,535	.79	8.66	4.53	9.04	4.91
240	6.19	3.10	12,240	.47	5,620	1.02	6.66	3.57	7.21	4.12	2,620	.46	1,355	.89	6.65	3.56	7.08	3.99
300	4.95	2.48	11,800	.49	5,400	1.06	5.44	2.97	6.01	3.54	2,310	.52	1,200	1.01	5.47	3.00	5.96	3.49
360	4.12	2.06	11,350	.50	5,200	1.10	4.62	2.56	5.22	3.16	2,050	.59	1,060	1.14	4.71	2.65	5.26	3.20
420	3.54	1.77	10,860	.53	5,000	1.15	4.07	2.30	4.69	2.92	1,830	.66	950	1.27	4.20	2.43	4.81	3.04
480	3.09	1.54	10,300	.56	4,800	1.19	3.65	2.10	4.28	2.73	1,645	.74	860	1.41	3.83	2.28	4.50	2.95
540	2.75	1.38	9,600	.60	4,620	1.24	3.35	1.98	3.99	2.62	1,480	.82	780	1.55	3.57	2.20	4.30	2.93
600	2.48	1.24	9,300	.62	4,460	1.28	3.10	1.86	3.76	2.52	1,350	.90	720	1.68	3.38	2.14	4.16	*2.92*
660	2.25	1.12	8,880	.65	4,300	1.33	2.90	1.77	3.58	2.45	1,240	.98	660	1.83	3.23	2.10	4.08	2.95
720	2.06	1.03	8,450	.68	4,140	1.38	2.74	1.71	3.44	2.41	1,150	1.05	620	1.95	3.11	*2.08*	4.01	2.98
780	1.90	.95	8,040	.71	4,000	1.43	2.61	1.66	3.33	2.38	1,065	1.14	575	2.10	3.04	2.09	4.00	3.05
840	1.77	.88	7,680	.75	3,860	1.48	2.52	1.63	3.25	2.36	995	1.22	545	2.22	2.99	2.10	3.99	3.10
900	1.65	.82	7,340	.78	3,740	1.53	2.43	1.60	3.18	*2.35*	930	1.30	520	2.33	2.95	2.12	*3.98*	3.15
960	1.55	.78	7,000	.82	3,610	1.59	2.37	1.60	3.14	2.37	875	1.38	495	2.44	2.93	2.16	3.99	3.22
1,020	1.46	.73	6,700	.86	3,520	1.63	2.32	1.59	3.09	2.36	830	1.46	475	2.55	2.92	2.19	4.01	3.28
1,080	1.38	.69	6,480	.88	3,420	1.68	2.26	*1.57*	3.06	2.37	785	1.54	455	2.66	2.92	2.23	4.04	3.35
1,140	1.30	.65	6,220	.92	3,360	1.71	2.22	1.57	3.01	2.36	755	1.60	440	2.75	2.90	2.25	4.05	3.40
1,200	1.24	.62	6,020	.95	3,280	1.75	2.19	1.57	2.99	2.37	730	1.66	425	2.85	*2.90*	2.28	4.09	3.47
1,260	1.18	.59	5,840	.98	3,200	1.79	2.16	1.57	2.97	2.38	------	------	------	------	------	------	------	------
1,320	1.12	.56	5,680	1.01	3,140	1.82	2.13	1.57	2.94	2.38	------	------	------	------	------	------	------	------
1,380	1.08	.54	5,510	1.04	3,080	1.86	2.12	1.58	2.94	2.40	------	------	------	------	------	------	------	------
1,440	1.03	.52	5,380	1.07	3,010	1.90	2.10	1.59	2.93	2.42	------	------	------	------	------	------	------	------
1,500	.99	.50	5,220	1.10	2,960	1.94	2.09	1.60	*2.93*	2.44	------	------	------	------	------	------	------	------
1,560	.95	.48	5,100	1.12	------	------	2.07	1.60	------	------	------	------	------	------	------	------	------	------
1,620	.92	.46	4,960	1.16	------	------	2.08	1.62	------	------	------	------	------	------	------	------	------	------
1,680	.88	.44	4,860	1.18	------	------	2.06	1.62	------	------	------	------	------	------	------	------	------	------
1,740	.85	.42	4,760	1.20	------	------	*2.05*	1.62	------	------	------	------	------	------	------	------	------	------

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60	24.75	12.38	13,500	0.42	5,400	1.06	25.17	12.80	25.81	13.44	3,300	0.37	1,690	0.72	25.12	12.75	25.47	13.10
120	12.38	6.19	12,980	.44	5,200	1.10	12.82	6.63	13.48	7.29	3,110	.39	1,550	.78	12.77	6.58	13.16	6.97
180	8.25	4.12	12,480	.46	5,020	1.14	8.71	4.58	9.39	5.26	2,930	.41	1,410	.86	8.66	4.53	9.11	4.98
240	6.19	3.10	12,000	.48	4,850	1.18	6.67	3.58	7.37	4.28	2,750	.44	1,275	.95	6.63	3.54	7.14	4.05
300	4.95	2.48	11,550	.50	4,680	1.22	5.45	2.98	6.17	3.70	2,580	.47	1,155	1.05	5.42	2.95	6.00	3.53
360	4.12	2.06	11,140	.51	4,500	1.27	4.63	2.57	5.39	3.33	2,410	.50	1,050	1.15	4.62	2.56	5.27	3.21
420	3.54	1.77	10,740	.53	4,310	1.33	4.07	2.30	4.87	3.10	2,240	.54	950	1.27	4.08	2.31	4.81	3.04
480	3.09	1.54	10,360	.55	4,150	1.38	3.64	2.09	4.47	2.92	2,075	.58	875	1.38	3.67	2.12	4.47	2.92
540	2.75	1.38	9,960	.58	3,990	1.44	3.33	1.96	4.19	2.82	1,920	.63	800	1.51	3.38	2.01	4.26	2.89
600	2.48	1.24	9,600	.60	3,840	1.49	3.08	1.84	3.97	2.73	1,775	.68	750	1.61	3.16	1.92	4.09	*2.85*
660	2.25	1.12	9,240	.62	3,680	1.56	2.87	1.74	3.81	2.68	1,640	.74	700	1.73	2.99	1.86	3.98	2.85
720	2.06	1.03	8,880	.65	3,540	1.62	2.71	1.68	3.68	2.65	1,520	.80	665	1.82	2.86	1.83	3.88	2.85
780	1.90	.95	8,520	.67	3,400	1.69	2.57	1.62	3.59	*2.64*	1,410	.86	630	1.92	2.76	1.81	3.82	2.87
840	1.77	.88	8,200	.70	3,250	1.76	2.47	1.58	3.53	2.64	1,315	.92	605	2.00	2.69	*1.80*	3.77	2.88
900	1.65	.82	7,880	.73	3,150	1.82	2.38	1.55	3.47	2.64	1,230	.98	585	2.07	2.63	1.80	3.72	2.89
960	1.55	.78	7,580	.76	3,050	1.88	2.31	1.54	3.43	2.66	1,160	1.04	570	2.12	2.59	1.82	3.67	2.90
1,020	1.46	.73	7,300	.78	2,960	1.94	2.24	1.51	3.40	2.67	1,100	1.10	555	2.18	2.56	1.83	3.64	2.91
1,080	1.38	.69	7,020	.82	2,880	1.99	2.20	1.51	3.37	2.68	1,050	1.15	540	2.24	2.53	1.84	3.62	2.93
1,140	1.30	.65	6,760	.85	2,800	2.05	2.15	*1.50*	3.35	2.70	1,000	1.21	525	2.30	2.51	1.86	3.60	2.95
1,200	1.24	.62	6,500	.88	2,720	2.11	2.12	1.50	3.35	2.73	960	1.26	515	2.35	2.50	1.88	3.59	2.97
1,260	1.18	.59	6,280	.91	2,660	2.15	2.09	1.50	3.33	2.74	930	1.30	500	2.42	2.48	1.89	3.60	3.01
1,320	1.12	.56	6,060	.95	2,600	2.20	2.07	1.51	3.32	2.76	900	1.34	490	2.47	2.46	1.90	*3.59*	3.03
1,380	1.08	.54	5,860	.98	2,550	2.25	2.06	1.52	3.33	2.79	875	1.38	480	2.52	2.46	1.92	3.60	3.06
1,440	1.03	.52	5,700	1.01	2,500	2.29	2.04	1.53	3.32	2.81	850	1.42	470	2.57	2.45	1.94	3.60	3.09
1,500	.99	.50	5,540	1.03	2,460	2.33	2.02	1.53	3.32	2.83	835	1.45	--------	--------	2.44	1.95	--------	--------
1,560	.95	.48	5,400	1.06	2,420	2.37	2.01	1.54	3.32	2.85	815	1.48	--------	--------	*2.43*	1.96	--------	--------
1,620	.92	.46	5,300	1.08	2,390	2.40	2.00	1.54	3.32	2.86	795	1.52	--------	--------	2.44	1.98	--------	--------
1,680	.88	.44	5,180	1.11	2,370	2.42	1.99	1.55	3.30	2.86	775	1.56	--------	--------	2.44	2.00	--------	--------
1,740	.85	.42	5,090	1.13	2,340	2.45	1.98	1.55	3.30	2.87	755	1.60	--------	--------	2.45	2.02	--------	--------
1,800	.82	.41	5,000	1.15	2,310	2.48	*1.97*	1.56	*3.30*	2.89	740	1.64	--------	--------	2.46	2.05	--------	--------

[1] Average actual skidding distance is half the maximum actual distance, or 60 per cent of the maximum direct distance from stump to railroad.
[2] Maximum direct skidding distance is taken as distance between spurs since on these slopes skidding is from one side of slope only. Costs vary directly with area served and stand per acre.
[3] Output (taken from figs. 19, 22, 28 and 30) is per hour at average skidding distance (60 per cent of maximum direct) and costs per thousand feet board measure. Cost is figured by dividing crew cost by output per effective hour for each distance. Crew costs are figured from cost tables given in appendix.
[4] Figures in italic indicate the actual skidding distance at which all factors combine to produce the lowest total cost.

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Output or costs for swamping, skidway construction, and tailing down on skidways have not been included in these tables. These operations, if properly organized, do not materially affect the cost of skidding and accordingly do not influence the proper spacing of the railroad spurs or transportation routes. The comparisons assume, as is ordinarily the case, that timber skidded by tractor is felled downhill, limbed, topped, and skidded in tree lengths, whereas that skidded by horses is in logs averaging about 16 feet.

The points of chief interest brought out in the preceding tables are shown in condensed form in Tables 8 and 9. In Table 8 is given, for the various slopes, seasons, and timber sizes, the point at which, and the width of strip or zone within which, the timber may be skidded by either horse or tractor at approximately the same cost.

TABLE 8.—*Point and zone of equivalent cost as between tractor and horse skidding, under various operating conditions*

Operating conditions	Point of equal cost [1]	Zone of equal cost	Cost per M [2]
0 to 15 per cent slope:			
Summer work—	*Feet*	*Feet*	*Dollars*
3 to 5 log timber	210	350	0.56
9 to 12 log timber	270	450	1.07
Winter work—			
3 to 5 log timber	270	450	.64
9 to 12 log timber	330	550	1.16
15 to 30 per cent slope:			
Summer work—			
3 to 5 log timber	270	450	.49
9 to 12 log timber	330	550	1.08
Winter work—			
3 to 5 log timber	390	650	.52
9 to 12 log timber	480	800	1.38

[1] Beyond distances given, tractor skidding is more economical; short of these distances horse skidding has the advantage.
[2] Cost at point of equivalence or average cost for zone.

TABLE 9.—*Most economical distances between railroad spurs and the most economical direct-skidding distances; and the combined cost per thousand of railroad construction and skidding*

Operating conditions	Stand per acre	Tractor skidding		Horse skidding	
		Distance between railroad spurs [1]	Combined cost	Distance between railroad spurs [1]	Combined cost
0 to 15 per cent slope:	M ft. *b. m.*	*Feet*	*Dollars*	*Feet*	*Dollars*
Summer work—					
3 to 5 log timber	10	2,800	1.52	2,000	2.02
	20	2,000	1.18	1,200	1.49
9 to 12 log timber	10	2,400	2.09	1,600	2.56
	20	1,800	1.71	1,200	1.94
Winter work—					
3 to 5 log timber	10	3,400	1.50	2,200	1.88
	20	2,400	1.22	1,400	1.46
9 to 12 log timber	10	3,000	2.09	1,600	2.51
	20	2,000	1.76	1,200	1.91
15 to 30 per cent slope:					
Summer work—					
3 to 5 log timber	10	5,800	2.05	4,000	2.90
	20	3,600	1.57	2,400	2.08
9 to 12 log timber	10	5,000	2.93	3,000	3.98
	20	3,000	2.35	2,000	2.92
Winter work—					
3 to 5 log timber	10	6,000	1.97	5,200	2.43
	20	3,800	1.50	2,800	1.80
9 to 12 log timber	10	6,000	3.30	4,400	3.59
	20	2,600	2.64	2,000	2.85

[1] Twice the maximum direct distance.

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The figures in Table 8 illustrate again the effect of slope, season, and size of timber upon the relative efficiency of tree-skidding methods. Slopes of 15 to 30 per cent, winter work, and small timber tend to favor the horses. In other words, the point of equal cost for skidding with horses and tractors will be advanced as slope increases, timber becomes smaller, or weather conditions change from summer to winter.

As an example, Table 8 shows that 3 to 5 log timber can be skidded in summer over 0 to 15 per cent slopes for a distance of 210 feet at the same cost per thousand for horses and tractor. For shorter distances, skidding with horses is cheaper, and for greater distances skidding with tractors is cheaper. On the same slope, under winter conditions, the distance at which the cost is approximately identical increases from 210 to 270 feet for 3 to 5 log timber and from 270 to 330 feet for 9 to 12 log timber. On steeper slopes (15 to 30 per cent) 9 to 12 log timber can, under winter conditions, be skidded a distance of 480 feet for the same cost per thousand with either horses or tractors. This means that under winter conditions skidding can be more cheaply done with horses for distances up to 480 feet and more cheaply with tractors for all greater distances.

Table 8 also indicates the desirability of giving thorough consideration in the planning of an operation to the possibilities of securing a lower average cost per thousand from stump to landing by the use of a combination of skidding methods.

The combined cost figures given in Table 9 show the relative effect of slope, season, and size of timber upon the combined cost of railroad construction for each of the two methods of skidding. On either slope the spread between costs by the two methods is greater for summer than for winter conditions and greater for three to five log timber than for the smaller size. It will be noted that the costs of handling the 9 to 12 log timber under winter conditions, particularly on the steeper slopes, favor horse work. Were smaller logs being considered, the relatively greater cost for tractor work, due to these conditions, would be brought out even more forcibly.

It is, of course, evident that the several items making up the total costs of skidding by horse and tractor will vary in their relation from year to year for the same operating conditions. For example, the price of hay and oats might go up while that of gasoline and oil might decline. Sufficient change might occur in the cost of certain items to shift the points at which the costs of the two methods are the same. This variation is brought out in additional computations comparing the costs of the two methods after a 7-year interval. The 3-year average cost per effective hour of the horse skidding unit for 1927–1929 is 16 per cent less than that for the period 1920–1922. The cost per effective hour of the tractor-skidding organization, on the other hand, decreased 25 per cent during the same period.

Because of this unequal decrease in the cost per effective hour over the same period of years, the distance at which the cost per thousand of the two methods is the same has been reduced an average of 90 feet for the several different conditions given in Table 8. The greater reduction in the cost per effective hour of the tractor-skidding unit is due to improved machines sold at a much lower

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price than formerly and to lower consumption per hour of gasoline, oil, and grease, all of which also declined in price. During this period (1927 to 1929) good teams were inclined to increase in value, as did hay and oats. The reduction in the cost per effective hour during the 7-year period for the horse-skidding unit is due almost entirely to a decrease in labor costs.

Tables 8 and 9 illustrate the way in which output data can be applied to operating problems. They could easily be refigured to fit the conditions of any specific problem.

OUTPUT DATA AS A GUIDE TO PROPER UTILIZATION STANDARDS

Logging-output data not only serve as the basis for a more profitable logging operation but also make possible the setting up of effective utilization standards for the individual operation, by means of which it should be possible to leave the forest land in a much better productive state. The most profitable method of operation is often the least destructive and therefore the one in which both the operator and the public should have the greatest interest.

Table 10 indicates the possibility of determining utilization standards. The variation in output and cost from stump to landing or mill is here shown for timber ranging in size from 2 to 22 logs per thousand feet. These figures are based on a horse operation for nearly level areas and steep slopes, at average skidding distances of 200 feet and of 1,800 feet. Thus the influence of slope and distance upon the cost of logging different sizes of material is indicated. Table 10 also brings out more forcibly than do Tables 8 and 9 the difference in output caused by the factor of slope.

TABLE 10.—*Relative output per hour and cost per thousand feet board measure of horse logging large and small timber at different distances and over different slopes*

Size of timber (logs per M)	Sawing		Swamping		Loading		Unloading		Autotruck haul, 1 mile		Total pre-skidding cost
	Output	Cost	Output	Cost	Output	Cost	Ourput	Cost	Output	Cost	
	Ft. b. m.	*Dollars*	*Ft. b. m.*	*Dollars*	*Ft. b. m.*	*Dollars*	*Ft. b. m.*	*Dollars*	*Ft. b. m.*	*Dollars*	*Dollars*
2	1,260	0.86	1,650	0.26	10,950	0.26	18,400	0.08	3,600	0.86	2.32
3	1,280	.85	1.500	.28	10,900	.26	18,600	.07	3,600	.86	2.32
4	1,230	.88	1,350	.31	10,700	.27	18,400	.08	3,500	.88	2.42
5	1,180	.92	1,200	.35	10,200	.28	17,800	.08	3,300	.94	2.57
6	1,130	.96	1,050	.40	9,600	.30	16,800	.08	3,100	1.00	2.74
7	1,060	1.03	930	.46	8,800	.32	15,400	.09	2,860	1.08	2.98
8	1,030	1.06	830	.51	8,000	.36	13,500	.10	2,650	1.16	3.19
9	990	1.10	740	.57	7,250	.39	11,600	.12	2,500	1.24	3.42
10	950	1.15	670	.63	6,600	.43	10,200	.14	2,400	1.29	3.64
11	900	1.21	620	.69	6,000	.48	9,200	.15	2,300	1.34	3.87
12	860	1.27	580	.73	5,550	.51	8,500	.16	2,200	1.40	4.07
13	820	1.33	540	.79	5,200	.55	8,000	.17	2,150	1.44	4.28
14	790	1.38	500	.85	5,000	.57	7,600	.18	2,100	1.47	4.45
15	760	1.43	460	.92	4,800	.59	7,300	.19	2,050	1.51	4.64
16	740	1.47	430	.99	4,650	.61	7,000	.20	2,000	1.54	4.81
17	720	1.51	400	1.06	4,520	.63	6,800	.20	1,950	1.58	4.98
18	700	1.55	380	1.12	4,400	.65	6,700	.21	1,920	1.61	5.14
19	680	1.60	360	1.18	4,350	.66	6,600	.21	1,900	1.63	5.28
20	660	1.65	340	1.25	4,300	.66	6,500	.21	1,880	1.64	5.41
21	640	1.70	320	1.33	4,250	.67	6,500	.21	1,860	1.66	5.57
22	620	1.75	300	1.42	4,200	.68	6,450	.22	1,850	1.67	5.74

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TABLE 10.—*Relative output per hour, etc.*—Continued

Size of timber (logs per M)	Horse skidding								Total logging cost			
	Skidding 0–15 per cent slope				Skidding 30–50 per cent slope				0–15 per cent slope		30–50 per cent slope	
	200 feet		1,800 feet		200 feet		1,800 feet					
	Output	Cost	Output	Cost	Output	Cost	Output	Cost	200 feet	1,800 feet	200 feet	1,800 feet
	Ft. b. m.	*Dolls.*	*Ft. b. m.*	*Dolls.*	*Ft. b. m.*	*Dolls.*	*Ft. b. m.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
2	2,650	0.46	425	2.85	3,500	0.35	900	1.34	2.78	5.17	2.67	3.66
3	2,430	.50	400	3.02	3,100	.39	825	1.47	2.82	5.34	2.71	3.79
4	2,200	.55	375	3.23	2,725	.44	750	1.61	2.97	5.65	2.86	4.04
5	2,000	.60	350	3.46	2,400	.50	675	1.79	3.17	6.03	3.07	4.36
6	1,840	.66	325	3.72	2,150	.56	625	1.94	3.40	6.46	3.30	4.68
7	1,660	.73	300	4.03	1,930	.63	575	2.10	3.71	7.01	3.61	5.08
8	1,530	.79	275	4.40	1,750	.69	525	2.30	3.98	7.59	3.88	5.49
9	1,430	.85	250	4.84	1,600	.76	480	2.52	4.27	8.26	4.18	5.94
10	1,340	.90	240	5.04	1,460	.83	440	2.75	4.54	8.68	4.47	6.39
11	1,260	.96	230	5.26	1,330	.91	400	3.02	4.83	9.13	4.78	6.89
12	1,180	1.03	220	5.50	1,220	.99	375	3.23	5.10	9.57	5.06	7.30
13	1,120	1.08	210	5.76	1,110	1.09	350	3.46	5.36	10.04	5.37	7.74
14	1,070	1.13	200	6.05	1,020	1.19	325	3.72	5.58	10.50	5.64	8.17
15	1,020	1.19	190	6.37	950	1.27	300	4.03	5.83	11.01	5.91	8.67
16	980	1.23	180	6.72	880	1.38	275	4.40	6.04	11.53	6.19	9.21
17	940	1.29	170	7.12	820	1.48	250	4.84	6.27	12.10	6.46	9.82
18	900	1.34	160	7.56	770	1.57	240	5.04	6.48	12.71	6.71	10.18
19	860	1.41	150	8.07	710	1.70	225	5.38	6.69	13.35	6.98	10.66
20	820	1.48	140	8.64	650	1.86	200	6.05	6.89	14.05	7.27	11.46
21	790	1.53	130	9.31	600	2.02	190	6.37	7.10	14.88	7.59	11.94
22	760	1.59	130	9.31	560	2.16	175	6.91	7.33	15.05	7.91	12.65

The ratios of cost per thousand of handling 22-log timber and 2-log timber (taking the latter as unity) for the various phases of the logging operation, are as follows:

Sawing	2,0
Swamping	5,5
Loading autotrucks	2,6
Unloading autotrucks	2,8
Skidding, 200 feet easy slopes	3,5
Skidding, 1,800 feet easy slopes	3,3
Skidding, 200 feet steep slopes	6,2
Skidding, 1,800 feet steep slopes	5,2

In these ratios the influence of distance is shown by a comparison of costs in Table 10. Although the cost of skidding 2-log timber on a gentle slope is 6.2 times as great at 1,800 feet as at 200 feet, 22-log timber costs only 5.9 times as much at the greater distance. On a steep slope the big-timber ratio is 3.8 and the small timber ratio only 3.2. This shows that the short haul has less effect in modifying the cost of logging small timber than it has in the case of large timber.

The influence of slope upon the output for large and small timber is shown in Table 10. At the 200-foot distance the case of skidding 2-log timber on the 0 to 15 per cent slope is 1.3 times that for the 30 to 50 per cent slope, and that for the 22-log timber is less, in the ratio of 0.7 to 1. A similar comparison at 1,800 feet indicates that at this distance slope ceases to favor large logs to quite the same degree. The cost for the large timber here is 2.1 times as much on the 0 to 15 per cent slope as on the 30 to 50 per cent slope, whereas that for the 22-log timber is 1.3 times as much on the gentle as on the steeper slopes.

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At this point, consideration should be given to the relation of defect to size of timber. This may be very strikingly illustrated. On the 0 to 15 per cent slope with a 200-foot skidding distance, it is evident that timber of 2-log per thousand size can be handled for as low a net cost when 71.3 per cent defective as can perfectly sound timber running 22 logs per thousand under the same conditions. With the same slope at the 1,800-foot distance, the defect in the 2-log timber might be 69.4 per cent. The possible defect would be 84.0 and 80.6 per cent, respectively, for the 200 and 1,800-foot distances on the 30 to 50 per cent slope.

The effect of slope and distance on the cost of the total operation (horse skidding) from stump to landing or mill is also shown in Table 10. Skidding by tractor instead of horses tends to favor large logs more at longer distances and on the lesser slopes.

Table 11 illustrates the effect of different cutting methods upon the logging cost. A typical ponderosa pine stand located in western Montana was selected for the application of these logging-cost data. The original estimate sheets covered an area of 440 acres. The timber was uneven aged, trees in all the 2-inch diameter classes from 10 to 40 inches being represented. The stand per acre averaged 12.17 trees 10 inches and over in diameter, containing 8,993 board feet. The diameter of the average tree in the stand was slightly under 24 inches, and the timber as a whole ran seven and one-half logs to the thousand.

TABLE 11.—*Comparison of horse-logging costs under clean cutting and diameter-limit cutting*[1] *on 440 acres of ponderosa pine in western Montana*

Diameter breast high (inches)	Volume average tree [2]	Trees per acre	Volume per acre	Size of timber [3]	Logging costs under clean cutting: Skidding 200 feet, 0–15 per cent slope: Per M ft. b. m.[4]	Skidding 200 feet, 0–15 per cent slope: Per acre	Skidding 1,800 feet, 30–50 per cent slope: Per M ft. b. m.[4]	Skidding 1,800 feet, 30–50 per cent slope: Per acre
	Bd. ft.	*Number*	*Bd. ft.*	*Logs per M*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
10	60	0.20	12	50.0	13.20	0.16	29.00	0.35
12	94	.84	79	33.0	9.70	.77	19.05	1.50
14	101	.80	81	25.0	8.00	.65	14.35	1.16
16	249	1.45	361	20.0	6.90	2.49	11.45	4.13
18	328	*1.18*	*387*	14.0	5.60	*2.17*	8.15	*3.15*
20	484	1.61	779	11.0	4.80	3.74	6.90	5.38
22	586	1.32	774	9.0	4.25	3.29	5.95	4.60
24	757	1.64	1,241	7.0	3.70	4.60	5.10	6.33
26	976	1.64	1,601	6.0	3.40	5.44	4.70	7.52
28	1,234	.77	950	4.8	3.10	2.94	4.30	4.08
30	1,565	.39	610	4.0	3.00	1.83	4.05	2.47
32	1,940	.18	349	3.5	2.90	1.01	3.90	1.36
34	2,282	.09	205	3.0	2.85	.58	3.80	.78
36	2,523	.30	757	2.7	2.85	2.16	3.75	2.84
38	3,060	.11	337	2.4	2.80	.94	3.70	1.25
40	3,330	.14	466	2.2	2.80	1.30	3.65	1.70
Total or average	708	12.66	8,989	7.5	3.80	34.07	5.40	48.60
Under diameter limit cutting [1]	--------	8.19	8,069	--------	--------	27.83	--------	38.31
Difference in volume and cost	--------	4.47	920	--------	--------	6.24	--------	10.29
		Per cent	*Per cent*			*Per cent*		*Per cent*
Reduction	--------	35.3	10.2	--------	--------	18.3	--------	21.2

[1] Leaving 10 to 18 inch trees uncut.
[2] Volume of average tree for each diameter class.
[3] Number of logs per thousand for different tree diameters obtained from Figure 4.
[4] Cost for sizes over 22 logs per thousand from Table 10 values curved.

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Assuming an average skidding distance of 200 feet and slopes of 0 to 15 per cent, a clean cut of the area, involving the removal of all trees 10 inches and over in diameter, would cost $34.07 per acre. A total volume of 8,989 board feet would be removed. If all 10, 12, 14, 16, and 18 inch trees were left uncut a volume of 8,069 board feet per acre would be removed at a cost of $27.83. This is a reduction of 35.3 per cent in trees logged, 10.2 per cent in volume, and 18.3 per cent in the cost of logging. In other words, by leaving 4.5 trees per acre containing a scale of 920 board feet a saving of $6.24 per acre in the cost of logging is obtained. With the extremes shown in Table 11 and an average skidding distance of 1,800 feet on 30 to 50 per cent slopes, a clean cut of the acre would remove the total volume of 8,989 board feet at a logging cost of $48.60. Cutting to a diameter limit of 20 inches, on the other hand, would leave 4.5 trees to the acre, ranging from 10 to 18 inches in diameter, and provide a cut per acre of 8,069 board feet at a cost of $38.31. This amounts to a 21.2 per cent reduction in logging costs for a 10.2 per cent reduction in volume. It should be stated here that certain logging costs, such as charges for improvements and administration, have not been included in either Table 10 or 11. These costs are not reduced in total by a smaller cut and therefore the charge per thousand feet increases as the volume to be removed decreases. Owing to the small volume involved in Table 11 these charges would have but little effect upon the total logging cost and may be disregarded in the comparisons.

The comparison afforded in Table 11 is presented merely as an indication of the effect of different cutting limits on the cost of logging alone. There are, even here, several factors which must be considered if the most economical operation is to be made possible. The younger or smaller trees to be left in selective logging should vary in size according to the slope of the timbered areas and also the distance which the logs are skidded over that slope. This point is clearly illustrated in Table 11. Sixteen-inch trees skidded a distance of 200 feet on 0 to 15 per cent slopes can be logged for $6.90 per thousand. It will cost $11.45 per thousand to log trees of the same size when skidded a distance of 1,800 feet over 30 to 50 per cent slopes. It may be possible, therefore, to log sound 16-inch trees of good quality that stand within an average skidding distance of 200 feet from the landing, on 0 to 15 per cent slopes, and impractical, from an economic standpoint, to cut the same size and type of tree when it occurs far up on steep slopes a long distance from the landing. The percentage of defect in different-sized logs, which determines whether such logs can be profitably taken or should be left in the woods, also varies with distance and slope.

In determining the proper method of selective cutting to make possible the most economical operation, the value of the products cut from trees of different sizes and the lumber-manufacturing cost, as well as the logging cost, must be considered. Manufacturing costs, like logging costs, increase as the size of the timber decreases. In most species of timber the products cut from small trees are less valuable per thousand feet than those cut from large trees. Detailed information is now available on the production costs and value of the products by tree sizes for a number of the more important timber

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species in several of the lumbering regions.[6] With such information available, it is now possible not only to place logging and milling operations on a more profitable basis by selective cutting but to keep large areas of timberlands productive through a sustained-yield system of management.

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[6] Much of the material covering the effect of tree size on production costs is not yet in print. Titles at present available include:

ASHE, W. W.
1926. RELATION OF SIZE OF TREE TO LOGGING COSTS, STUMPAGE VALUES, AND PROFITS. Amer. Lumberman 2683: 73–74.

———
1930. SMALL TREES WASTEFUL TO CUT FOR SAW TIMBER. U. S. Dept. Agr. Leaflet 55, 5 p., illus.

BRADNER, M., and FULLAWAY, S. V., JR.
1927–28. SIZE OF TIMBER, AMOUNT OF DEFECT—IMPORTANT FACTORS IN LUMBERING: AN ANALYSIS OF THEIR EFFECT UPON PRODUCTION COSTS AND VALUES AND THEIR CONSEQUENT INFLUENCE ON PROFITABLE TREE AND LOG UTILIZATION IN THE INLAND EMPIRE. Timberman 29 (2): 38–40, 44–48; (3): 40–46; (4): 62–63; (6): 162–174.

BRUNDAGE, M. R., KRUEGER, M. E., and DUNNING, D.
1933. THE ECONOMIC SIGNIFICANCE OF TREE SIZE IN WESTERN SIERRA LUMBERING. Univ. Calif. Agr. Exper. Sta. Bul. 549, 61 p., illus.

GARVER, R. D.
1927. SMALL SAWMILL UTILIZATION OF SHORTLEAF PINE. Lumber Trade Jour. 92 (9): 40–41.

———
1930. SELECTIVE LOGGING OF SOUTHERN PINE. Lumber Trade Jour. 97 (7): 34–35.

———
1930. SELECTIVE LOGGING VERSUS CLEAR CUTTING IN SHORTLEAF PINE. Lumber Trade Jour. 98 (8): 25–26, illus.

GIBBONS, W. H., JOHNSON, H. M., and SPELMAN, H. R.
1929–30. THE EFFECT OF TREE SIZES ON WESTERN YELLOW PINE LUMBER VALUES AND PRODUCTION COSTS. Timberman 30 (12): 44–48, 1929; 31 (1): 241–244; (2): 49–55; (3): 54–56; (4): 49–52; (5): 194–198, 1930.

ZON, R., and GARVER, R. D.
1927. SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE STATES, WITH SPECIAL REFERENCE TO THE COST OF HANDLING SMALL AND LARGE TREES. 23 p. Oshkosh, Wis.

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APPENDIX

RECOMMENDATIONS FOR THE CONDUCT OF LOGGING-OUTPUT STUDIES

GENERAL OBSERVATIONS

Some very definite considerations determine the feasibility and desirability of output studies in any branch of logging. The factors appreciably affecting output must be readily distinguishable and susceptible of classification both for the purpose of study and for application of the results. The particular activity must have a definite effect upon the cost of logging, and the output must not be dependent upon that of some other branch of the operation. If operating conditions are so well standardized that little or no knowledge would be added over that acquired through cost accounts, output studies are unnecessary. Methods and equipment not commonly employed, as well as any abnormal conditions, are naturally excluded.

In order that results may be applicable to specific conditions as found, the data must be collected, segregated, and compiled on the basis of definite natural factors which affect output and can be identified for classification. To insure permanency, all values which are subject to fluctuation, such as rate of pay, effective hours usually worked, and units of measurements for quantity of work done, must as far as possible be reduced to a constant by eliminating variable quantities. Further, to permit general application of logging-output data, only crews of standard size should be studied.

Many factors which influence output in certain branches of logging will be found to vary with the region. Sawing and skidding in the ponderosa pine type of Montana and California may be taken as an illustration of this point. If all factors now used as a basis for measuring output were identical in the two regions there would still be differences in output. These would result from other characteristics such as climate, general broad regional form and height of trees, and a different general class of labor. The combined influence upon output of these and other broad regional characteristics can be accounted for only by separate studies.

DEGREE OF REFINEMENT DESIRED

The extent to which the integral parts of any particular job can profitably be studied depends upon the number of variable factors involved and upon whether or not the conditions under which or the method by which the work is done can be corrected or changed along the lines indicated by the results of the study. When it is evident that output is governed by factors which can not be controlled, it is of no practical value to determine the individual effect of these factors on output.

The methods followed in gathering output data for felling and bucking are pertinent. For this branch of the operation the whole tree has been taken as a basis. Stopwatch determinations might be made of the time required for a saw crew to complete each of the minute parts of the work, such as gathering tools, walking from tree to tree, planning, swamping, barking, undercutting, wedging, oiling, etc. It has been found, however, that such information contains nothing of practical value. It was determined that for the same crew, the relative variation in time needed to perform similar details of the work was greater than the time used in completing similar units of work, each of which was composed of all these details. This is evident in view of the possible variations in the conditions under which the details of the work are carried out. With the whole tree as a basis, a loss in performing one of the details may be compensated for by a gain in others.

Some factors having a great effect on particular phases of the work are either intangible or impossible of classification. No two cuts in sawing are exactly

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alike. If the optimum height of log from the ground and position of the sawyer could be determined, the information would have no practical application. The conditions under which the work must be done could not be arranged to meet the specifications.

Time variations caused by the human element further increase the difficulty of obtaining representative figures. One crew will take more time in planning and save time in bucking. Another crew will use more time swamping, wedging, and oiling but conserve time or energy or both in the actual sawing. Very much the same variation was evident in the work of skidding with horses.

Therefore, to attempt the same refinement that has been applied in studies of many other industrial operations is futile in logging work. The elements of human judgment and skill, together with the inability to standardize conditions, enter so largely that even the closest study will not give reliable information. Refinement of methods used in these studies is therefore gauged by the nature of the work and the practical application of the results.

QUANTITY OF DATA REQUIRED

It is impracticable to set a definite standard as to the quantity of data that should be obtained to arrive at a reliable average ouput for any particular unit crew. This depends to a large extent upon how consistent the crews are in their work. Much less information is needed for crews of long-experienced woodsmen than for crews of inexperienced men. Another consideration of importance is the number of factors used as a basis for separating output, and over which the data collected must be distributed.

The number of units of organization which should be included in each set of data must be determined on the basis of possible variation between such units. Obviously the variation will be greatest in work into which the human element enters to the largest extent.

It has been found by experience about how many trees and trips and what scale or time are necessary under each column of the office summary sheet to give the corresponding point on the curve a reasonable degree of accuracy. This statement presupposes that field data have been accurately kept, and that all lost time not properly chargeable against particular units of work has been excluded. Determinations are then made for the average time and scale values of each column in the summary sheet, for work done in one class and under standard conditions according to the method of classification used.

An average of about 15 hours for each diameter class in sawing gives results of sufficient reliability. Thus, if sawing were done in a stand ranging from 12 to 40 inches in diameter, records covering about 15 hours' work on each of the 2-inch diameter breast high classes (15 in all), or a total of 225 hours of effective time, should be obtained. If timber varied from 12 to 20 inches in diameter, 135 hours would give results of equal value. In the former case, assuming the timber to average about 24 inches diameter breast high, scaling approximately 900 feet per tree, and the average output to be 1,100 feet per hour during the 225 hours or 30 days, observation would be made of about 250,000 feet or 275 trees for each curve. If the trees averaged larger than this, obviously the number studied in this time would be less but the total scale greater.

Skidding a distance of 100 feet would require about 15 team hours, provided that all the timber skidded fell into the same log class as, for example, the 3 to 5 or the 9 to 12 log per thousand class; for a 2,000-foot distance, about 150 to 200 hours' observation of one such unit would be necessary to attain a satisfactory degree of accuracy. Since the timber in this region is usually spread over four or five log classes, four or five times as many data, or about 750 to 1,000 team hours, would be required under each slope classification. With an average output of 600 feet per hour, 600 to 700 thousand feet would be the basis for each set of curves.

The more complex the method of transportation, the simpler becomes the gathering of reliable information, since under the complex methods performance is more constant. Thus, in progressing up the line from horse skidding toward railroad transportation, it is found that fewer and fewer data are necessary to establish reliable output.

The speed at which horses travel while skidding on the ground varies with the size of the load, the intangible differences between two skid trails over

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apparently similar surfaces, the time of day, the distance of haul, temperature, etc. What horses will do at one distance is not reliable indication of what they will do at another. Some of these variables are eliminated in hauling with drays or trailing in chutes. Notwithstanding, observations are still necessary at frequent intervals to take up the intangible variations. In chute trailing, the rate of travel is fairly constant; distance covered by each item is made quite uniform through relaying, and the time spent in hooking the loads varies less than in skidding, where chaining or dogging the logs is a different problem for each load.

With power-driven equipment, owing to the fact that travel is over roads from which a large majority of the variables have been eliminated and that the logs have been freed from contact with and influence of surface conditions, the rate of travel loaded and empty, size of load, and loading time become relatively constant. For these integral parts of the operation it therefore becomes possible to determine averages which will have common application; those determined for one distance may be applied to any distance.

This method of obtaining averages for component parts of the operation has been used in the studies of autotruck hauling. Observations made at a few different distances have been expanded to cover any desired distance. The same methods have been used in sleigh hauling and chute trailing, with somewhat less accurate results.

From this discussion it becomes obvious that the amount of data needed per unit of distance hauled decreases as the distance increases. The longer the haul, the greater the reduction of variables in the methods commonly employed.

UNITS OF MEASUREMENT

In conducting logging-output and time studies of this character, pages 4 and 5 should be carefully read, and the basic units of measurement therein described should be used unless a better and more logical classification can be devised.

ORGANIZATION AND EQUIPMENT OF STANDARD CREWS

In determining the make-up of crews of standard size only those men are included whose work directly affects the output. For sawing, either contract or day work, the output per hour rests definitely upon the work of two men. Team and teamster and swamper are taken as the unit crew in contract horse skidding. Sometimes one-half the time of chainer or dogger is included. Under day work, swampers are not included, as swamping is usually done in advance and therefore does not interfere with skidding output. In contract work the teamster often assists in swamping. Thus output rests somewhat on the swamper. Brush conditions also are a factor. Output studies have not been made on operations where the team must wait a considerable proportion of the time on the swamper, since this is not considered a representative way of doing the work. In swamping alone, in brush disposal, grading, or any other job performed independently, one man is taken as a unit.

Tractor skidding is based on the work of 10-ton machines with a crew of either two or three men. Some operations necessitate only a driver and a chokerman. In others a chaser is added to the crew. This varies with the nature of the terrain and size of timber. On level open ground with large timber, only two men are needed. Where a bunching team and teamster are used in the woods, they become a part of the unit crew. A team and teamster used on the landing are not considered a part of the crew. These have no influence on output and are generally required only because of the loading method in use.

A standard organization for trailing in chutes is one man and team. A teamster and two or four horses make up the crew in sleigh hauling.

Autotrucks used for hauling logs in this region are commonly of 5-ton or 7½-ton capacity.

The unit for ground donkey skidding includes the entire crew whether the work is on a contract or day basis. This unit has been adopted because, for example, the output of the loading crew is entirely dependent on the one donkey skidding to a certain landing, whereas the loading crew in tractor or horse skidding operations is usually loading from several skidways to which a number of units are skidding.

The landing saw crew is taken as part of the unit crew in donkey skidding but not in tractor work. In the former case the saw crew is an essential part of

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the organization, and its output is governed entirely by the donkey. In tractor work, bucking may be done on the landing, or the same saws may be cutting for two tractors or one tractor and several teams.

SEGREGATION OF DATA ACCORDING TO NATURAL FACTORS

The natural factors which have an important bearing on logging output and are used as a basis for the segregation of data are season, slope, surface, forest type, stand per acre, species, height, diameter, and windfall and brush.

FOREST TYPE

Type, by itself, has only a very general value in conveying information relative to logging output or costs. In conjunction with some of the more specific factors, however, it assumes greater importance and tends to give to each of these other factors a clearer definition by narrowing the margin of possible variation within them. A wide variation occurs in the height of western larch in the various types in which it is commonly found. In any specific forest type and region, however, the height variation is much less. It is for this reason that sawing output is divided for different types.

A type classification has other advantages. There are a number of undefinable elements such as soil, brush, windfall, and surface which usually differ with type. Taken individually, each has a rather small and intangible effect on the work; in the aggregate, as expressed in type, they constitute a noticeable factor. This can be readily illustrated.

The surface in a white pine or spruce type is often rough. The soil is soft, filled with roots, and subject to gouging. In a ponderosa pine type, as a rule, larger loads can be pulled over the gentler slopes because the surface is usually firm, smooth, and free from roots. Thus type has been made a factor in skidding.

Where these various elements are found to be the same in two types, the data are either combined or a study is made in but one type. In skidding, the types studied have been grouped as larch-Douglas fir type, white pine, and ponderosa pine type. Each type has been considered separately in compiling sawing data.

TIMBER SPECIES

The species is ordinarily made a basis of segregating output data for sawing, swamping, and brush disposal. Where white pine and white fir or spruce and balsam fir occur in the same type, they have been combined because the output for the two species in each group was practically the same. In other branches of logging the output for all species has been found to be about alike.

HEIGHT OF TIMBER

The effect of height on sawing is not shown specifically on the output graphs. It is accounted for within reasonable limits of variation by making individual curves for each species and each type by regions. An illustration of this point has been given in the discussion of forest type. For a given region, type within that region, and species, the variable of height is confined to a reasonable margin. Without further classification this factor becomes sufficiently specific for all practical purposes. This presupposes, of course, that data have been collected over sufficient exposures and sites to obtain a representative height.

STAND PER ACRE

A distinction in stand per acre has been made only for skidding, swamping, and brush disposal. In the other branches of operations covered by these studies stand has no appreciable effect; on the three mentioned it has but a small intangible influence. The classification of the average stand in which the operation is being conducted has been made on the basis of 5 to 10, 10 to 20, 20 to 40, and over 40,000 feet board measure per acre.

SIZE OF TIMBER

Two classifications are made the basis of recording size of timber. In sawing, the diameter breast high of each tree to the nearest tenth of an inch is recorded, together with the length and gross scale of each log. This gives

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the total height utilized and the total scale. The logs per thousand for each diameter class may thus be computed.

For all skidding or moving operations the length and scale of each log are recorded in terms of gross scale per hour of effective time. The number of logs and total gross scale for each trip or other unit of work are kept separate. From these data the average size or logs per thousand for each trip is computed.

The material is divided, according to size, into groups of 1 to 2, 3 to 5, 6 to 8, 9 to 12, 13 to 17, 18 to 25, and 26 or more logs per thousand feet board measure of cut. Output is shown on the basis of these classes. The 6 to 8 logs per thousand class in the output graphs may include logs scaling anywhere from 2 to 20 per thousand but averaging for one trip or load somewhere between 5.6 and 8.5 per thousand. These are the limits of the 6 to 8 log class. These data can be employed in determining the output for any body of timber where the average run of logs is known, through the use of a curve representing such size. Interpolation must be made for sizes which can not be read directly from the curves.

SLOPE

For certain branches of the operation, slope has been classified in different divisions according to its relative effect on the work and to the method of operation employed. In the field work, slopes are read as percentages with the Abney level and recorded by the groups into which they fall.

The slope classifications used in sawing, swamping, and brush disposal are 0 to 30, 30 to 50, and over 50 per cent. It has been found that a finer distinction is unnecessary and tends to complicate the work of the studies. Not until slope exceeds 30 per cent has it any appreciable influence on the output of these phases of logging.

For skidding with horses or tractors by any method in which the source of power itself moves between the stump and the landing, the following divisions of slope have been adopted: 0 to 15, 15 to 30, 30 to 45, and 45 to 60 per cent downhill, and 0 to 15 per cent uphill. The range includes the slopes over which skidding by these methods is commonly carried on. Very little uphill skidding is ever done by any of these methods, except over short distances below railroad spurs or chutes.

The skidding trip from stump to landing is in most cases over a slope which does not vary more than 15 per cent from the maximum to the minimum. Often, however, this 15 per cent range will not coincide with the classification given. In this event, the entire slope is thrown into the slope group which it most resembles and which is most influential in determining the output. A specific example will illustrate this.

Skidding is being done over a total distance of 1,000 feet. Six hundred feet of this is on a 10 per cent slope; the other 400 feet is on a 25 per cent slope. The classification here would ordinarily be the 15 to 30 per cent group. One reason for this is because the weighted average slope is 16 per cent. But another fact is of importance in establishing the slope classification. In actual practice, smaller loads would be skidded over the 25 per cent slope than would be the case if the entire 1,000 feet were on this slope. On the other hand, the loads for the distance over the 10 per cent slope would be larger than if the entire skidding distance was on a 10 per cent slope.

It is, of course, necessary to use judgment in deciding upon slope classification. No skidding trip is made over a slope exactly the same for the entire distance. This is the principal reason for the rather broad classification. Such a basis was essential to its practical application. In cases where there was a considerable difference in the percentage of slope for several portions of the skidding distance, a separate record was kept of the time and amount skidded over each section. At the time of the office compilation it was possible to decide on the most logical slope classification. This would be based on the condition which contributed most to controlling the output. If skidding was done for 300 feet over a 40 per cent slope and then for 500 feet over a 10 per cent slope, two trips might be necessary over the latter distance to handle one trail of logs brought in over the 40 per cent slope. It is readily seen that the 10 per cent slope would largely be the controlling factor. Classification would be made accordingly.

For sleigh hauling, chute trailing, and draying, slopes of 0 to 5, 5 to 10, and 10 to 15 per cent with distance for each are recorded. Nearly all sleigh haul-

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ing is done over slopes from 0 to 15 per cent. A 3 to 5 per cent slope is most nearly ideal. Greater slopes, within moderation, do not have any effect on output. More sandmen would of course be required. By far the greatest factor in sleigh hauling is the kind of winter weather. This is a rather indefinable factor which can be treated in only a very general manner at best.

Autotrucks are normally used for hauling only on slopes of between 5 per cent uphill and 10 per cent downhill. Records were made in the field showing separately the total distance traveled with load over uphill slopes of 0 to 5 per cent and over downhill slopes of 0 to 5 and 5 to 10 per cent. Trucks equipped with 4-wheel brakes are sometimes operated on downhill slopes to a maximum of 25 per cent. No such slope conditions were encountered in these studies, however. No distinction is made in the difference in slope or distance of the return empty which is nearly always made over the same route. Output figures are segregated by types of road, as dirt, plank, and pole roads.

The influences of slope conditions on ground skidding with a donkey are many and varied as compared with horse skidding in the same type of country. With steam power the logs are skidded up and down hill, and at every imaginable angle along the sides or diagonally across the slopes. Little sidehill skidding is necessary with horses or tractors, owing to the comparatively small cost of constructing landings and of moving equipment. Most of the timber is moved almost straight downhill; very little is taken uphill. Even skidding along the sidehill with these two methods does not present the difficulties from logs rolling or hanging up behind stumps that are usual in ground yarding with donkeys.

In donkey skidding, it has been assumed that the difference in output due to skidding up, down, or along the side of a hill is not sufficient to justify segregation for slopes under 30 per cent. The classification so far used, though it has not been experimented with to any extent, is: Uphill 30 per cent to downhill 30 per cent; uphill 30 to 50 per cent; uphill 50 to 70 per cent; downhill 30 to 50 per cent.

WINDFALL AND BRUSH

Brush and windfall are reported as lacking or as light, medium, or heavy, in comparison with the average quantities for the type in this region. The condition as to brush and windfall is used as a basis of showing separate output for sawing, swamping, brush disposal, and contract horse skidding. In other methods of skidding, swamping is either done in advance or not at all and has little influence on output results. The condition is, however, recorded and shown on all graphs as a matter of general information.

SURFACE

Surface conditions are not differentiated in relation to output, because the difference caused by the greatest variation encountered in these studies was not appreciable. Classification of surface is in general terms, such as smooth or rough, and is used simply to indicate the nature of the area. In sawing, particularly, a rough surface in light stands decreases output and loss from breakage is greater. Logs must frequently be cut shorter than would be necessary had the break not occurred.

SEASON

Weather conditions have a variable and extremely important influence on the output of nearly all branches of logging work. No operator can afford to ignore them. On two chances, similar in every respect, one operator will be forced to cease operations on account of weather conditions whereas the other will not only be able to continue but will turn the conditions to his advantage.

In a logging chance on which half the timber is on level ground and half on slopes ranging from 30 to 50 per cent, weather conditions should receive thorough consideration when the operation is planned. Logging the steep slopes during the summer months and the flat ground in winter will make the work not only continuous but cheaper.

Provision should be made to take advantage of seasonal changes, in so far as they can be anticipated, and to regulate seasonal output accordingly. Little consideration can be given to minor variations in weather; adjustment must be based on broad classifications on the basis of average summer and average winter conditions. No attempt is made to show production as affected by

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changes within the seasons in spite of the great influence these exert over short periods. Instead, an average is obtained by carrying the study over a period sufficient to include a fair representation of such conditions within the region.

In collecting the data it was found necessary to draw a rather arbitrary line between summer and winter conditions. Winter conditions were assumed to exist whenever the logs could be skidded without gouging through the frozen ground or snow to the soft earth beneath, when timber becomes frozen, or when the snow is deep enough to interfere with sawing. A daily record was kept in camp of the depth of snow, of whether the ground was frozen or soft, and of the temperature.

FIELD RECORDS AND EQUIPMENT

For gathering data in the field, two sets of records are used. The first set, for the actual field work, is in notebook form. Figures 49 and 50 show samples of such forms, which are the usual type of notebook sheet.

DATE _____ TYPE _____ OPERATION _____

Species	D.B.H (in.)	Time of start	Time on tree (min.)	LOG Length (feet)	LOG Gross scale (10 feet b.m.)	Tree scale (10 feet b.m.)	Top diameter (in.)	Slope (per cent)	Brush	Surface
White Pine	26	8.20	50	16	30	97	9	20	H	R
				16	28					
				16	21					
				14	14					
				16	4					
		9.10	5	Lost time - resting						
White Fir	32	9.15	75	16	38	158	6	10	m	S
				16	33					
				10	19					
				6	11 - Break					
				16	24					
				16	16					
				14	10					
				16	6					
				12	1					
		10.30								

FIGURE 49.—Record form for sawing data

In the use of these forms, the beginning of any unit of work, lost time, or quitting time is recorded to the nearest even minute under "Time of start." The difference between the time of starting one thing and of starting the next is recorded in minutes, not hours and minutes, in the next column, opposite the time of its start. When the day's work is finished, the record indicates what was done every minute of the day from the time the tools were picked up until they were put away. Following the "Trip time" or "Tree time," there is either a record of the unit of work accomplished or an explanation of the disposition made of that time.

In sawing, the length and gross scale for every cut are given. This applies whether the piece is a merchantable log, a cull, or a break which is trimmed. If no cut is made where the break occurs, whether in the top or elsewhere, the piece is scaled as though it would make a merchantable log. In this manner the composite effect of breakage, for the conditions existing on any particular chance, is taken into consideration. This record of breakage and top diameter makes possible the construction of a volume table based on actual utilization. The percentage of breakage may also be determined. Should it be desired to base the volume table on a specific top diameter, a record can be made of the length of the top piece, to this diameter, left in the woods.

In the use of the skidding form the actual distance traveled along the slope while under load (not the horizontal distance), if 100 feet or more, is recorded for each trip to the nearest even 100 feet; anything less than 50 feet is recorded as 25 feet. Long distances, where appreciable error is apt to occur in pacing, are chained and marked up on stumps or stakes for future reference.

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The second set of records is made up of camp summary sheets, on which are recorded the total or average daily records. These sheets are also used for the collection of data on other jobs, particularly swamping, as these data

DATE _____

TYPE _____ BRUSH _____ WINDFALL _____ OPERATION _____

Time of start	Trip time	Distance skidded (feet)	Slope (per cent)	LOG Length (feet)	LOG Gross scale (10 feet b.m.)	Trip scale (10 feet b.m.)	Logs (number)	Size of tree (logs per M)
8.00	20	300	25	16	18	38	3	6-8
				16	16			
				14	4			
8.20	32	500	25	12	3	19	4	17-25
				18	5			
				16	8			
				16	3			
8.52	23		Lost	time -	repairing	rigging		
9.15								

FIGURE 50.—Record form for skidding and hauling data

may be collected in conjunction with the regular output work. Figure 51 indicates the nature of this sheet.

By changing headings or adding others for number of men on loading or unloading crew, road monkeys, or sprinkler and rutter crew and teams, this form may also be used to record any desired information with autotruck or sleigh haul or may be adapted to any study.

A daily record is kept also of the distance to work, method of travel, conditions of road or trail, etc. From these data the number of effective hours for any job can be closely estimated.

Date	Effective time (hours)	Total camp scale (10 feet b.m.)	Unit crews (number)	Swampers (number)	Chainmen (number)	Tail-down men (number)	Weather conditions

FIGURE 51.—Camp summary form for skidding and draying operations

The equipment necessary to carry on the field studies is as follows: Accurate timepiece, scale rule—Scribner decimal C, steel tape (100 feet and menders), diameter tape (20 feet), Abney level (per cent), notebook, and timber crayon.

The diameter tape is used to determine diameters of logs which can not be scaled directly with the rule.

PERSONAL REQUIREMENTS

It is essential that men detailed to output studies have a genuine interest in them and that they place reliance on the general principles upon which such studies are based. Without this viewpoint, it is doubtful whether anyone conducting observations over any length of time will continue to maintain the necessary degree of accuracy after the novelty of the work wears off. The men must also, as in any work of this nature, have the proper conception of the value of accuracy and detail.

A majority of workmen, especially woodsmen, object to stop-watch methods. Tact and diplomacy is necessary in association with both laborers and supervisory staff. The observer must refrain from statements that are liable to affect

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the normalcy of output. Experience in several specific cases has shown that men have either speeded up or slowed down as the result of unconsidered statements, thus making the data collected worthless and misleading.

The observer should make no remarks, criticisms, or suggestions to the workmen in regard to their methods, output, scale, wages, or piece rate. He should collect information on what they do, as they do it. The camp foremen should be given nothing which will lead to a comparison of the work of two crews. Also, no new ideas on methods of conducting the specific operation need be offered to the foreman. There is ordinarily a good deal more to be learned from this individual than can be told him. The old-time practical logger in charge of an operation has his head full of practical, everyday, common-sense ideas. He knows how to get his work done without too many preliminaries. He likes rule-of-thumb and short-cut methods. The observer should not try to convert him but should study his methods of accomplishing his ends and learn to apply as far as possible, what is good in them. There is no man more generous in his impulses and more willing to help anyone who is ambitious and sincere in his efforts to learn the practical side of logging than this old, experienced logging foreman.

Work performed by any individual crew or unit of organization should not be divulged to any one connected with the operation. If the men doing the work realize that this is the policy, there will ordinarily be no objection to the methods followed in these studies and men will work at a normal pace.

Ordinarily, someone with considerable experience in work of this kind should spend a day or two with men starting out for the first time on this work or changing to a new job with which they have had no experience. In that length of time it is possible to explain on the ground, during the actual process of collecting the data, the instructions needed by the observer. Periodic visits to each man are made every month or six weeks. Doubtful points, which frequently come up during the course of the work, are taken up and a general inspection and check of the work accomplished are made.

COMPILATION OF DATA

The working up of the field notes into final form consists, briefly, of the following steps.

(1) Determining the logs-per-thousand group of each load or trip.

(2) Transferring to large tabulation sheets the time and scale under their proper diameter breast high columns for sawing, or distance for skidding or hauling, and then finding the total of this time and scale.

(3) Distributing the total lost time by prorating it against the total working time to which it is chargeable.

(4) Finding the gross output per hour for each diameter class or distance and evening-off the results by drawing a curve through these values plotted on cross-section paper.

Where logs are skidded or hauled with horses in lengths as actually bucked, the number of logs per thousand in the lengths as handled is the element of size that governs output. Calculation is, therefore, made on the basis of the actual number of pieces it will take to make a thousand feet, without reference to the run of the timber in standard 16-foot logs. In tractor or donkey skidding, timber is handled in double-length logs, or often in tree lengths. Bucking into short logs takes place on the landing or in the mill. Size of material in this case is determined and expressed in terms of the number of standard 16-foot logs per thousand feet irrespective of lengths into which these are bucked. This distinction is made because in tractor or donkey skidding the logs can be bucked into any lengths without materially influencing the output. In horse logging this would not be true.

A number of unit crews may be working together, making the output of any one somewhat dependent upon the others, as where several teams are skidding to the same landing or several auto trucks are hauling between the same loading and dumping grounds. The work of such unit crews should be summarized together. On work where each unit is entirely independent of the output of others and in which the period of time over which observations were carried on is not approximately the same, results of each must be summarized and the output of each first determined separately. A flat average of all is then found. To summarize the time and scale for all units together would be to weigh the output of each on the basis of the amount of data obtained for

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each crew. If the crew with the greatest output was observed over the longest period of time, values would be abnormally high and not representative of the average crew.

When the data are transferred from the field notes to the summary sheets, a separate summary sheet is provided for each set of conditions, each sheet bearing the heading of but one type, season, slope, log group, and so on.

Lost time, concerning all work done under conditions which go into the same curve or set of curves, is added together and not separated by logs per thousand for transportation or by species for sawing.

Table 12 has been prepared to show that in ordinary stands of timber it is unnecessary to consider diameter classes separately in computing output from the graphs. However, in stands having two distinct size-classes of timber it is necessary to give separate consideration to each of the groups.

TABLE 12.—*The computation of logs per thousand for sawing* [1]

Diameter breast high [2] (inches)	Trees	Logs per tree	Total logs	Gross volume per tree	Total volume	Gross output per hour [3]	Sawing time
	Number	*Number*	*Number*	*Ft. b. m.*	*Ft. b. m.*	*Ft. b. m.*	*Hours*
14	10	4	40	210	2,100	600	3.5
16	15	5	75	340	5,100	740	6.9
18	20	5	100	410	8,200	850	9.6
20	30	6	180	580	17,400	945	18.4
22	10	6	60	690	6,900	1,030	6.7
24	10	7	70	970	9,700	1,100	8.8
26	5	7	35	1,170	5,850	1,160	5.0
Total	100		560		55,250		58.9

[1] The totals in columns 4 and 6 indicate the average logs per thousand to be approximately 10. Reference to fig. 1 will show that white pine timber 20 inches in diameter will yield 10 logs per thousand. The total of column 6 divided by that of column 8 gives 938 feet as the weighted average output per hour of all diameter classes. Fig. 1 shows the output per hour for timber 20 inches in diameter or 10 logs per thousand to be about 945 feet. This indicates that, in ordinary stands of timber, it is unnecessary to consider diameter classes separately. However, in stands, for example, having a large percentage of the volume in 14 and 16 inch trees and the balance in trees from 36 to 40 inches, it is necessary to give separate consideration to each of these groups.

[2] White pine stand on best site.

[3] Output taken from fig. 1.

LABOR AND SUPPLY COST TABLES

In figuring the cost per thousand in any of the phases of the logging operation covered by the output graphs the wages of the different classes of woods workers employed or the cost per effective hour or day of the unit crew or organization used in doing such jobs are necessary information. For those using the output data in this bulletin who do not have at hand such information, Tables 13 to 20, giving wage or unit costs, have been prepared. These tables give the wages per hour, day, or month as the case may be of the several classes of woods workers, as well as the cost per effective hour or day of the unit crew employed in doing a specific piece of work. The tables are based on "Inland Empire" wages and supply costs for periods of one to three years from 1927 to 1929, inclusive. In case the labor and supply costs given in the tables do not apply at the time it is desired to use the output data, similar tables can be prepared on the basis of the wages and cost of supplies prevailing at a particular time.

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TABLE 13.—*Sawing and hauling crew costs per effective day, based on five different estimates of freight and handling charges on provisions and supplies* [1]

Freight and handling charges per pound	Cost of saw crew [2]			Cost of team and teamster [3]		
	1929 average	2-year average	3-year average	1929 average	2-year average	3-year average
No cost [4]	$8.40	$8.40	$8.40	$6.50	$6.60	$6.60
0.5 cent	8.70	8.70	8.70	7.30	7.40	7.40
1 cent	9.00	9.00	9.00	8.00	8.10	8.20
1.5 cents	9.20	9.20	9.20	8.70	8.80	9.00
2 cents	9.50	9.50	9.50	9.50	9.70	9.70

[1] This table is based on "Inland Empire" wages and team expenses for periods of 1 to 3 years, and on months of 24 effective days.

[2] Includes cost of files, oil, and a proportionate charge for time of filer, but does not include depreciation on saws and other tools. In 1929 at least 90 per cent of all the sawing in the "Inland Empire" was contract work at a cost of $1 to $1.45 per thousand for short logs. Contract felling and topping for tractor skidding costs between 50 and 90 cents per thousand. To the contract price must pe added the cost of saws and other tools, oil and saw filing, and depreciation on the tools, which run about as follows per thousand: Saw and other tools, 9 cents; files and oil, 2 cents; saw filing, 8 cents; and depreciation on tools, 6 cents.

[3] Includes barn care, medicine, shoes, nails, veterinary services, board and loss on board, and a normal amount for idle teams that averages about 12 to 15 per cent of the total; depreciation on horses and harness not included; 40 pounds of oats and 60 pounds of hay per day per team.

[4] Except such costs as are incurred on account of time of barn boss, bull cook, and clerk; applicable to camps so located that there are no other freight or handling charges; seldom used.

TABLE 14.—*Cost of logger-type, 10-ton tractor and driver per effective day* [1]

Item	Cost
Driver	$6.50
Gasoline	9.00
Oil and grease	2.00
Maintenance	7.50
Total	25.00

[1] The above is a weighted average based on 2,400 effective days in western Montana. Depreciation is not included in the above table. The life of a logging tractor should be figured as 4 years logging and a residual value of 20 per cent. This gives a straight depreciation of 20 per cent per year and amounts to about $5 per effective day. The above costs are for ponderosa pine skidding. Drivers' wages are for effective days only and 10 hours' time. Wages, repairing, and all parts are charged to maintenance. Gasoline, oil, and other supplies were brought in by logging train or autotruck. The above costs are figured on gasoline at a price of 18 to 22 cents per gallon, oil at 70 to 75 cents per gallon, and grease at 16 to 19 cents per pound. Effective days per year 180 to 235 with an average of 200. Days laid up for repairing or repairs average 20 to 30 per year.

TABLE 15.—*General wages of woods labor* [1]

Position	Range—1929 average	Position	Range—1929 average
Locomotive engineer	$5.00–$6.00	Cant-hook men	$3.40–$4.00
Locomotive brakeman	3.80– 4.50	Swampers	3.20– 3.60
Locomotive firemen	3.60– 4.20	Common labor	3.20– 3.40
Jammer engineer	5.25– 6.00	Tractor engineer [2]	6.00– 7.00
Jammer hooker	3.40– 4.00	Chokerman	3.80– 4.50
Top loader	3.80– 4.50	Teamster	3.60– 4.00

[1] Rate per 8-hour day.

[2] Includes overtime repairing or greasing.

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TABLE 16.—*General wages of administrative men*[1]

Position	1929 average wage	Position	1929 average wage	Position	1929 average wage
Logging superintendent	$400	Blacksmith	$135	Night watch	$95
Logging foreman	195	Machinist	180	Supply man	200
Straw boss	135	Barn boss	105	Scaler	145
Handy man	80	Bull cook	95	Clerk	150

[1] Rate per month, including cost of board; the 2-year and 3-year averages are practically the same as those for 1929.

TABLE 17.—*Unit cost of organization for horse skidding*

Unit	Cost per 8-hour day	Cost per hour
Team depreciation and interest	$0.55	
Team and teamster	7.40	
One-half time of chainer or dogger	1.70	
Total	9.65	$1.21

TABLE 18.—*Unit cost of organization for tractor skidding*

Unit	Cost per 8-hour day	Cost per hour
Tractor depreciation and interest	$5.15	
Gasoline, oil, and grease	11.00	
Maintenance	7.50	
Driver	6.50	
Total	30.15	
Tractor unit	30.15	
Choker man	4.15	
Total	34.30	$4.29
Tractor unit	30.15	
Choker man	4.15	
Chaser	4.15	
Landing team and teamster	7.40	
Total	45.85	5.73
Tractor unit	30.15	
Choker man	4.15	
Swamper	3.40	
Total	37.70	4.71
Tractor unit	30.15	
Choker man	4.15	
Swamper	3.40	
Bunch team and teamster	7.40	
Total	45.10	5.64

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TABLE 19.—*Unit cost of organization for loading autotrucks or sleighs*

Unit	Cost per 8-hour day	Cost per hour
Top loader	$4.15	
Two hookers	7.40	
Team and teamsters	7.40	
Tail-down man	3.70	
Total	22.65	$2.83

TABLE 20.—*Unit cost of organization for autotruck haul*

Unit	Cost per 8-hour day	Cost per hour
Driver, wages and board	$6.20	
Depreciation	5.00	
Interest	.74	
Insurance	2.00	
Repairs	6.00	
License	.20	
Gasoline at 10 cents per mile [1]	2.40	
Tires at 8 cents per mile	1.92	
Oil and grease at 1 cent per mile	.24	
Total	24.70	$3.09

[1] 12 trips per day, 2 miles per trip.

GLOSSARY OF LOGGING TERMS USED [7]

Bunch team.—A team used to bunch logs in one place for skidding or loading.

Chain.—A short length of chain used to fasten around a log or bunch of logs for skidding with horses.

Chainer.—One who places the chain around the log or bunch of logs in skidding.

Choker.—A short piece of cable or wire rope used in the form of a noose so that the log may be hooked to the tractor or donkey for skidding.

Choker man or choker setter.—The member of a skidding crew who fastens the choker on the log.

Chaser.—A member of a tractor skidding crew who accompanies the tractor with its load of logs from the woods to the landing to assist along the way and to unhook the chokers at the landing and see that they are returned to the woods with the tractor.

Crosshaul.—A method of loading and decking logs by use of a chain or cable set across the load through a snatch block. The end of the loading chain or cable may be equipped with either swamp hook or crotch chain. The power is generally supplied by horses or small tractor.

Deck up, to.—To pile logs upon a skidway.

Dog.—A short heavy piece of steel bent and pointed at one end with an eye or ring at the other. Two dogs connected by a short length of chain are used to hook logs together end to end to form a trail of logs for horse skidding.

Dogger.—One who connects the logs together end to end by means of dogs.

Dray.—A single sled, or two wooden sled runners with a crownpiece, slipped under one end of a bunch of logs for dragging.

Hang up, to.—To fell a tree so that it catches against another instead of falling to the ground.

Gin pole.—A pole secured by guy ropes, to the top of which tackle for loading logs is fastened.

Gyppo. Gyppo logging.—Small-scale contract logging; for example, when a large company contracts with a gyppo and his crew to log outlying sections that with the standard crew and equipment would be handled less economically.

[7] The definitions are given with special reference to their meaning as used in the "Inland Empire" region.

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Horse jammer.—A single pole or arrangement of poles equipped with loading tackle and used with horse power to load logs on sleighs, autotrucks, or cars. An end horse jammer loads from a position at the end of the sleigh, autotruck, or car.

Jig team or make-up team.—A team of horses used in making up a trail of logs in a chute at a skidway, landing, or point of entrance.

Plank road.—A road constructed by placing parallel three or more poles of medium size lengthwise along the road and covering crosswise with 3 to 6 inch planking. Additional planks are sometimes laid lengthwise on top of these for the tread. The road is used to haul logs with autotrucks.

Pole road.—A road constructed of poles for hauling logs with autotrucks. Four poles (two on each side) are laid lengthwise upon mudsills or cribbing. The outside poles are hewed to a flat surface to form the tread or track.

Road monkey.—A woods laborer who keeps a logging road in proper condition for operation.

Rutter.—A form of plow for cutting ruts in a sleigh road for the runners of the sleds to run in.

Rutter crew.—The driver of the team that draws the rutter, and a helper who assists in seeing that the ruts are properly cut in depth and line.

Sustained yield.—Cutting a forest at a rate not exceeding the production capacity of the area, thus giving a continuous and regular output of forest products

Swamper.—A woods laborer who cuts out the skidding trail and trims the limbs from the log preparatory to skidding.

Tail down, to.—To roll logs on a skidway to a point on the skids where they can be easily reached by the chuting, fluming, or loading crew.

Trail of logs.—Two or more logs dogged together end to end, for horse skidding or lying end to end to make up a load for trailing in a chute.

Whistle punk or signal man.—One who transmits orders from the foreman of the yarding crew to the engineer of the yarding engine.

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YELLOW POPLAR CHARACTERISTICS, GROWTH AND MANAGEMENT

BY

E. F. McCARTHY

Formerly Director Central States Forest Experiment Station
Forest Service

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 356 June, 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

YELLOW POPLAR CHARACTERISTICS, GROWTH, AND MANAGEMENT

By E. F. McCarthy [1]

Formerly *Director Central States Forest Experiment Station,* [2] *Forest Service*

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INTRODUCTION

Yellow poplar [3] (*Liriodendron tulipifera* L.) is a tree of paradoxes, even in name; throughout the South and wherever its wood products are used it is known as yellow poplar, but it is not in any sense a poplar; horticulturally it is perhaps best known as tuliptree, but it is not related to the tulips; its botanical name of "tulip-bearing lily tree" is in itself a paradox. Characteristics of the tree of a paradoxical nature have in the past proved baffling to foresters and disconcerting to timberland owners interested in the production of the species and its continued growth on their forest lands. Yellow poplar is one of the most adaptable of trees, having maintained its individuality intact all the thousands of years since Cretaceous times;

[1] The writer acknowledges his indebtedness especially to the late W. W. Ashe, of the Forest Service, for the use of his manuscript report on yellow poplar, including the records of 21 yield plots used in the construction of yield tables; to O. A. Alderman, Assistant Forester, Ohio Agricultural Experiment Station, and K. A. Swenning, forester for the Mead Pulp & Paper Co., for assistance in the collection of yield data in Ohio; and to the division of forestry, Georgia College of Agriculture, for a similar service in Georgia. Thanks are also due the members of the staffs of both the Allegheny and Appalachian Forest Experiment Stations for their assistance in the preparation and review of this bulletin, as well as to members of the Central States Forest Experiment Station.

[2] Maintained in cooperation with the Ohio State University, Columbus, Ohio, and the Ohio Agricultural Experiment Station.

[3] Yellow poplar has been called tulip, poplar, tuliptree, tulip poplar, and whitewood. It should not be confused with the true poplars belonging to the genus Populus, and commonly known as poplar, cottonwood, aspen, etc.

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but it is at the same time one of the most capricious in its refusal to grow under a variety of circumstances which would be favorable to most other trees. In certain rather extensive areas within the range of its best growth, not a single specimen of this species can be found; on the other hand, at the very limits of its reported natural range yellow poplar trees are found in full development and better than average growth. Yellow poplar is a hardwood that floats almost as readily as a softwood. It is a valued special-use wood, and also an important wood of general utility. In the average timber stand yellow poplar either becomes one of the tallest species in the stand or will not grow at all. It is a prolific seeder, but also a very vigorous sprouter under certain circumstances. These and many other peculiarities of yellow poplar have led to misunderstanding of its

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FIGURE 1.—Leaf, fruit, and terminal buds of yellow poplar

requirements, a knowledge of which is of vital importance if the production of yellow poplar is to continue on a marketable basis.

Yellow poplar is very easily identified in the growing season because of the peculiar blunt or truncated appearance of the leaf, which terminates in a broad notch. (Fig. 1.) The leaf has four to six points and is 3 to 6 inches long and rounded at the base. It is a bright green in summer, turning to a strikingly clear yellow in the autumn; both surfaces are smooth. The flower is tuliplike in form and size, with six petals varying in color from a light yellowish green at the margin to deep orange at the center. It appears in May or early June and lasts but a week or two. The fruit is a conelike strobile composed of a central spike bearing winglike scales or carpels. In September or October, after the loosened carpels have been scattered by the wind, only the long, pointed central spikes and basal scales remain on the tree. The thumb-shaped terminal bud is inclosed in two scales which meet in a ridge.

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Early settlers quickly recognized the value of yellow poplar because its comparatively soft but strong and straight-grained wood could be worked easily and proved very serviceable. Its admirable qualities brought it later into favor for such uses as interior finish for houses, carriage bodies, and saddle frames.

The popularity of yellow poplar is well deserved. As a tree, it is characteristically a hardwood of large size and excellent form, and its growth is vigorous. The wood, with which are often marketed small quantities of evergreen and cucumber magnolia (*Magnolia grandiflora* L. and *M. acuminata* L.), is strong, straight grained, and free from knots. It seasons very well, developing a minimum of defects under ordinary practice; it glues easily; and it is one of the most satisfactory woods for taking paint, enamel, or stain. It has a great variety of uses, and its lumber is in many respects a wholly adequate substitute for softwood lumber. Yellow poplar is used for cabinetwork, interior trim, and siding; in furniture manufacture it is used for drawer bottoms, backing, plywood, core stock, and for enameled furniture of all kinds. It is also used for pulpwood and excelsior, and for veneer baskets, containers, boxes, and crates.

A report (*6*)[4] on the wood-using industries in North Carolina made some years ago gives the following distribution of the annual consumption of yellow poplar lumber:

	Per cent
Furniture	53. 99
Planing-mill products	14. 18
Boxes and crates	12. 78
Miscellaneous products (caskets and coffins, sash, doors and blinds, fruit and vegetable packages, vehicles and vehicle parts, fixtures, elevator and machine construction, chairs, shuttles, spools, and bobbins)	15. 52
Unclassified	3. 53

While this list reflects mainly the well-developed furniture industry of North Carolina, it shows also a diversity of products made from yellow poplar that is indicative of the wide usefulness of the species throughout this State and elsewhere.

In addition to its usefulness, yellow poplar commends itself to the owner of forest land within its range by reason of its vigorous growth and early development into marketable sizes. Despite its reputation as a species difficult to establish, the indications are, as this study will attempt to make clear, that, once yellow poplar is established, satisfactory growth can be obtained on any moist, well-drained soil of good depth, including many desirable sites on abandoned fields, with comparatively little difficulty and at small expense.

In addition to its more obvious good qualities, yellow poplar has distinctive value as a honey tree. According to J. I. Hambleton, of the Bureau of Entomology, a yellow poplar of less than 20 years of age will yield during the season approximately 8 pounds of nectar, equal to 4 pounds of honey. At 10 cents a pound for honey, a tree of this size may produce upwards of 40 cents a year revenue for the beekeeper, an income that compares very favorably with the returns to be gained from other yellow poplar products.

The need for a better understanding of what constitutes desirable practice in the management of yellow poplar stands is evident in the fact that the drain on present stands, which threatens to have a

[4] Italic numbers in parentheses refer to Literature Cited, p. 51.

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permanent effect upon its marketability, is almost entirely in the control of the timberland owner. Losses from disease and insects are negligible. Fire losses are at the present time moderate and can easily be reduced. The great need is for a cutting practice that will encourage and hasten new second-growth stands and, as far as possible, extend the area of these stands. Also, much can probably be done through artificial regeneration, if the requirements of the species are thoroughly understood. It is the purpose of this bulletin to assist the forest-land owner, particularly in the region of best growth of yellow poplar, to retain on a basis of permanent yield and to augment so far as possible his present stands of this species of considerable and increasing value.

DISTRIBUTION AND OCCURRENCE OF YELLOW POPLAR

RANGE

As is shown in Figure 2, yellow poplar is found extending throughout the eastern and central parts of the United States, north to Lake Ontario and Grand River, Mich.; south into northern Florida, but avoiding in general the uplands of the longleaf pine region; and west to include the Wabash and lower Mississippi Valleys. Within this range, the species is found at all altitudes up to about 1,000 feet in the northern part of the mountain and plateau regions and 4,500 feet in the southern. Above these altitudes the northern hardwoods predominate, and with these yellow poplar can seldom compete.

The designation on Figure 2 of a region of best growth is somewhat arbitrary. It is based rather upon the areas within which yellow poplar is found in sufficient quantity to render it potentially a profitable timber crop than upon the quality or size of timber grown within this region. Actually, the tree reaches approximately its best individual development in the lower Wabash Valley, and large, well-formed yellow poplar trees have been cut in the Finger Lakes district of central New York and in the Huron River Valley of Michigan. But individual scattered trees such as these can hardly be regarded as possible nuclei of cultivated, marketable stands. It is only within the so-called region of best growth that special effort and expense to cultivate and favor the extension of yellow poplar stands are justified at this time. Yellow poplar second growth is increasing, however, in northeastern Ohio on land formerly occupied by beech and sugar maple stands; and in northeastern Maryland, southeastern Ohio, western Kentucky, and northern Georgia good stands of second growth are to be found near the limits of best growth, giving every indication of a possible extension of the area of marketable production of yellow poplar in the future.

One very significant characteristic of the range of yellow poplar is that in many places where there is no apparent obstacle to its growth large areas are devoid of this species, as in Franklin and Pickaway Counties, Ohio, where soil and moisture conditions appear to be entirely favorable.

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OCCURRENCE OF OLD-GROWTH STANDS

The remaining old-growth stands of yellow poplar are largely restricted to the more inaccessible parts of the mountain and plateau areas from southeastern Pennsylvania and West Virginia, south to northern Georgia and Alabama, although some scattered trees are

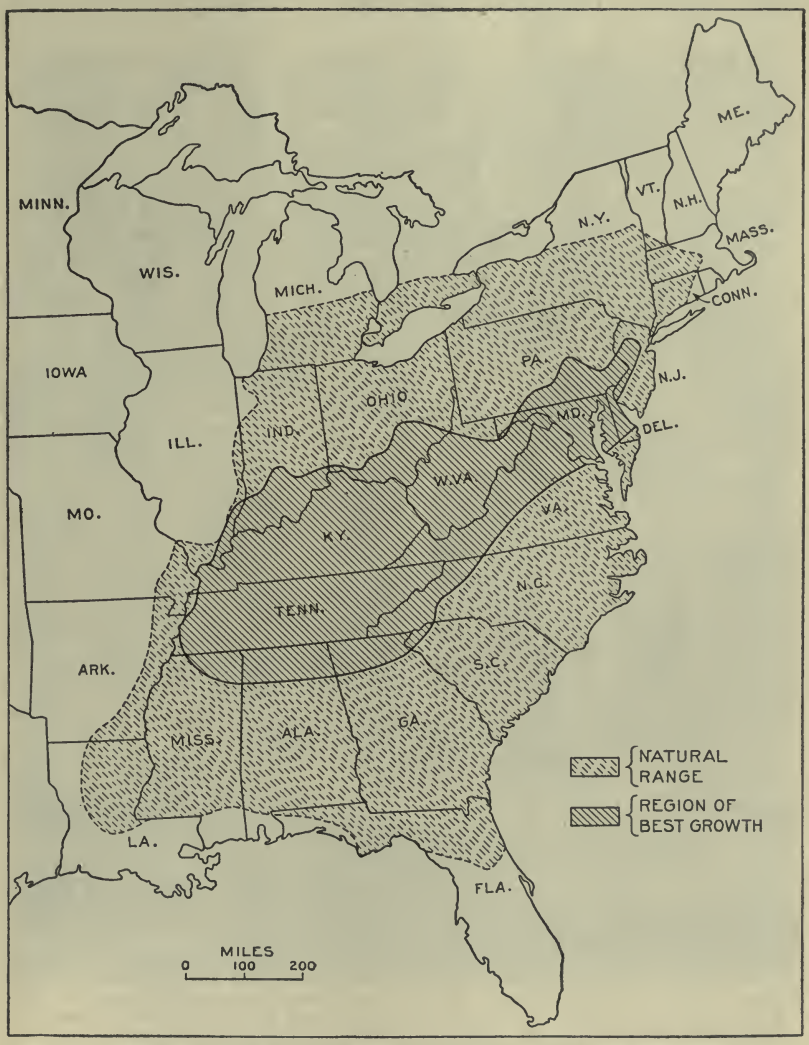

FIGURE 2.—Natural range of yellow poplar and region of best growth

still being logged from the swamps of the coastal plains, from the woodlands in the piedmont plateau, and in the Ohio drainage basin. (Figs. 3 and 4.) It is perhaps an exaggeration to refer to any of this old-growth yellow poplar as occurring in stands, since it appears universally as single trees or in small groups throughout this region and rarely forms pure stands even a few acres in size.

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On stream-bottom lands and the better drained soils of the swamp and overflow lands of the coastal-plain region, old-growth yellow poplar occurs in mixture with tupelo gum, swamp black gum, southern cypress, red gum, several species of oak, red maple, water ash, swamp cottonwood, and sometimes loblolly pine. In the overflow lands along streams in the piedmont plateau, associated species include red gum, black gum, red maple, American elm, and several

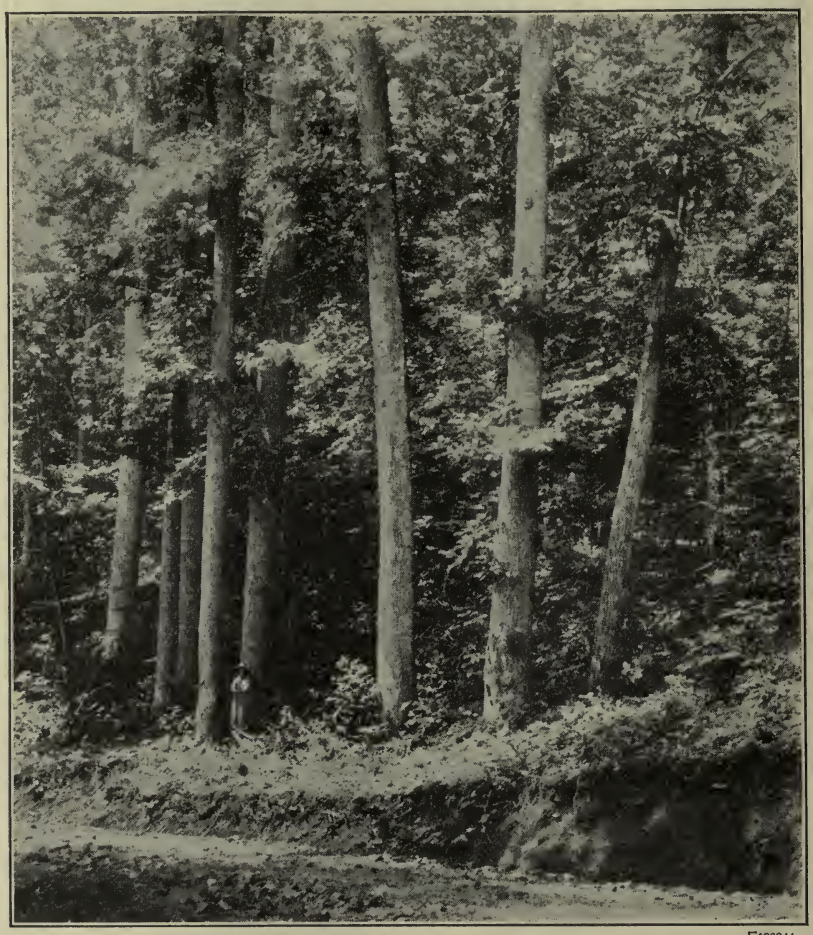

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FIGURE 3.—Old-growth yellow poplar on highway between Burton Lake and Hiawassee, Ga. This group is a part of an excellent natural stand in a north-facing cove. Size shown by man in left foreground

species of hickory. In both regions, yellow poplar comprises numerically only a small percentage of the stand but grows to large size and is valuable for lumber.

At lower elevations in the Appalachian Mountains and through the more rugged parts of the Cumberland and Allegheny Plateaus, where yellow poplar was once common in the coves and on moist slopes in mixture with many other hardwoods and a few conifers, it is

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still found singly or in groups in stands containing chestnut,[5] black locust, white oak, hemlock, northern white pine, and black walnut. Frequently the associated species include hickories, oaks, and yellow pines, as well as dogwood, sweet birch, black gum, silverbell, but-

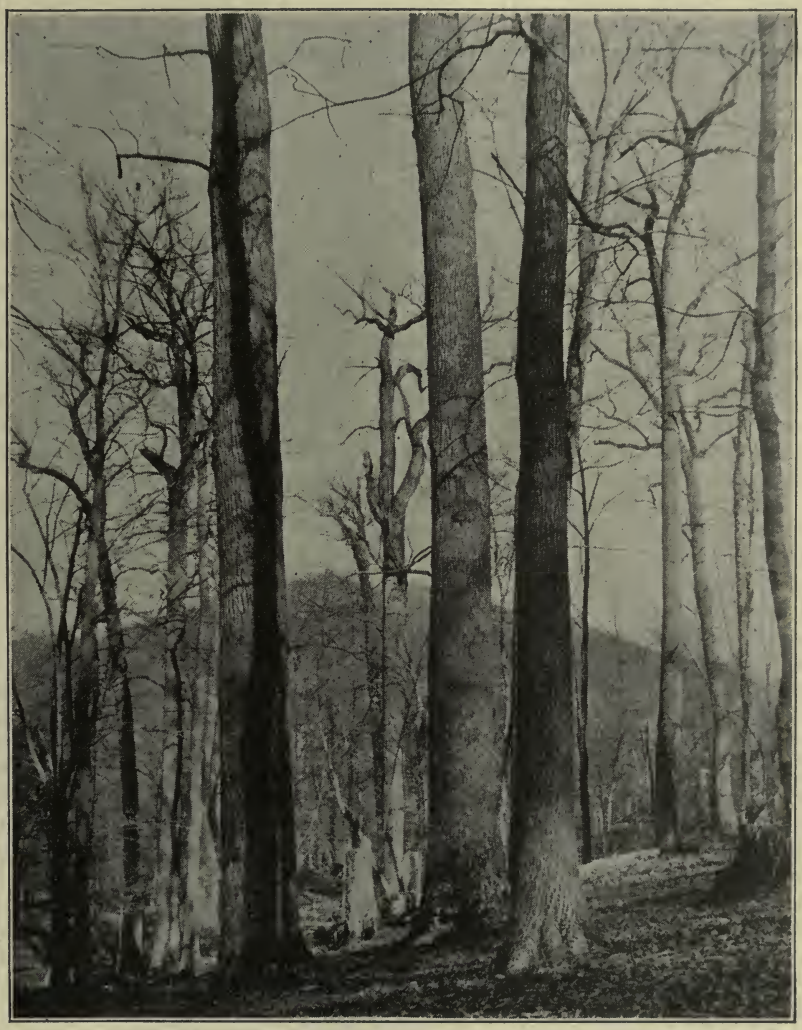

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FIGURE 4.—Old-growth yellow poplar located on a ridge top. In such locations poplar will not have as good form as when grown in the coves

ternut, basswood, and mountain magnolia. At higher elevations, especially in the higher part of the Allegheny Plateau, and also farther north, the associated species include red oak, white ash, black cherry, cucumber magnolia, slippery elm, buckeye (sp.), beech, sugar maple, and yellow birch.

[5] A list of the botanical names of species cited is given in the Appendix, p. 57.

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SECOND GROWTH

Second growth of yellow poplar is of two very distinct types. One of these is found on cut-over forest lands where the species grew originally and is now returning in mixture with other hardwoods. Yellow poplar occurs only scatteringly on any forest area where the cutting was in any manner selective, but on those lands where logging was delayed until the advent of logging railroads and where increased demand for the poorer species resulted in heavier cutting of the old growth, the new seedlings have found little competition from sprouts of other hardwoods and have held their own without difficulty against other seedling growth. In the last 30 years the best yellow poplar second growth in heavily forested sections has become established as the direct result of the heavy cutting of the old growth. Lack of seed trees has, however, prevented yellow poplar from covering many such openings.

The other type is found on abandoned fields where the new forest must start entirely from seed and under very different conditions of light, soil, and moisture from those in the virgin forest. On these old fields yellow poplar comes up practically even-aged and in much less complex mixture with other species. Such even-aged stands of yellow poplar are only found, however, where there was little serious interference from other growth in the seedling stage and where fire has been eliminated and grazing has been strictly controlled.

The greater part of the second growth in the mountain region has come up on old fields, some of which were abandoned at the time of the Civil War. Such tracts, generally of small size, are found in the cove heads or on the better benches and slopes. Where the soils of these clearings have not been too badly impoverished by erosion, yellow poplar seeds blown in from the surrounding forests find a favorable place for germination and growth. Where the seed was produced near by in sufficient quantities, yellow poplar eventually took possession of the greater part of these abandoned fields, overcoming successfully the competition of black locust, sassafras, staghorn sumach, and in some cases chestnut, which also grew from seed or sprouted after the fields were abandoned. These species, with silverbell, often form a large part of the crown cover during the first 10 years in the establishment of second-growth poplar on abandoned fields. Sumach is the first of the competitors to be killed out, and sassafras rarely holds a place in the dominant stand after 20 years. The other species remain to grow up with the yellow poplar and the mixture frequently includes some black cherry, black walnut, and white ash, as well as several species of pine. Slippery elm, black cherry, sugar maple, and red oak are common in the second growth at higher elevations, whereas on the drier slopes at lower elevations pitch pine, Virginia pine, and shortleaf pine are found.

Throughout the Eastern States, where chestnut was formerly abundant, yellow poplar seedlings are now frequently found in the openings caused by the death of chestnut, especially on the better sites.

The contrast between even-aged stands of yellow poplar on old fields and on clear cuttings is given in Tables 1 and 2 which show, respectively, the composition of second-growth stands on old fields in Union and Towns Counties, Ga., and that resulting from clear

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cutting for charcoal wood on lands of a coal and iron company near Cranberry, N. C.

TABLE 1.—*Composition of even-aged, second-growth yellow-poplar stands on old fields, north Georgia, on 10-acre basis* [1]

Diameter, breast high (inches)	Yellow poplar	Chestnut	Black locust	Pine [2]	Red oak	White oak	Black oak	White ash	Sassafras	Other species [3]	All species	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Per cent*
4	259.6	1.9	25.5	3.8	5.7	4.8	------	7.6	111.4	36.8	457.1	18
5	310.7	2.8	36.8	1.9	3.8	5.7	8.6	4.8	58.5	22.7	456.3	18
6	303.0	6.6	36.8	3.8	1.9	6.6	------	1.9	12.3	12.3	385.2	15
7	242.7	17.0	27.4	3.8	3.8	3.8	.9	4.8	7.6	5.7	317.5	12
8	190.7	11.3	25.5	.9	------	3.8	.9	.9	1.9	4.7	240.6	9
9	165.3	16.1	16.1	.9	1.9	.9	------	.9	.9	------	203.0	8
10	136.0	15.1	10.4	------	------	.9	------	.9	------	------	163.3	6
11	105.8	2.8	7.6	------	4.7	.9	.9	------	.9	.9	124.5	5
12	72.7	5.7	1.9	1.9	.9	------	------	------	------	------	83.1	3
13	42.5	3.8	1.9	------	.9	------	------	.9	------	------	50.0	2
14	36.9	5.7	2.8	.9	------	------	------	------	------	------	46.3	2
15	21.7	7.6	.9	------	------	------	------	------	------	------	30.2	1
16	13.2	9.4	------	.9	.9	------	------	------	------	------	24.4	1
17	8.5	.9	------	------	------	------	------	------	------	------	9.4	(4)
18	1.9	------	------	------	------	------	------	------	------	------	1.9	(4)
19	3.8	------	------	------	------	------	------	------	------	------	3.8	(4)
Total	1,915.0	106.7	193.6	18.8	24.5	27.4	11.3	22.7	193.5	83.1	2,596.6	------
Total per cent	74	4	8	1	1	1	(4)	1	7	3	------	100

[1] Computed from measurements on 26 sample plots totaling 10.59 acres. The stand averages 29 years old, ranging from 24 to 39 years.
[2] Virginia, shortleaf, and pitch pines.
[3] Includes hickory, red maple, silverbell, black gum, persimmon, sourwood, and post oak.
[4] Less than 0.5 per cent.

TABLE 2.—*Composition of even-aged, second-growth yellow-poplar resulting from clear cutting for charcoal wood, near Cranberry, N. C., on 10-acre basis* [1]

Diameter, breast high (inches)	Yellow poplar	Birch [2]	Beech	Black cherry	Chestnut	Ohio buckeye	Sugar maple	Black locust	Cucumber magnolia	Basswood	White oak	Hickory	Other species [3]	All species	
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*P.ct.*
2	9.8	174.0	396.0	7.5	3.8	90.0	111.0	------	3.0	2.2	6.8	4.5	42.0	850.6	17
3	42.8	174.8	210.0	4.5	5.2	67.5	59.2	0.8	5.2	4.5	7.5	1.5	35.2	618.7	13
4	89.3	201.0	147.8	10.5	13.5	99.0	57.8	.8	5.2	2.2	13.5	3.8	25.5	669.9	14
5	85.3	115.3	70.5	12.0	24.0	43.5	30.8	3.7	1.5	1.5	6.8	2.2	10.5	407.6	8
6	108.0	86.2	54.0	30.8	48.8	33.8	15.0	4.5	1.5	4.5	6.8	3.0	7.5	404.4	8
7	122.2	40.5	36.0	18.0	37.5	10.5	5.2	3.7	1.5	1.5	12.0	2.2	11.2	302.0	6
8	200.2	38.2	34.5	27.0	62.2	13.5	3.8	3.7	.8	2.2	10.5	4.5	15.0	416.1	8
9	156.0	9.0	5.2	14.2	30.0	9.8	2.2	3.0	2.2	3.0	2.2	2.2	3.8	242.8	5
10	178.5	9.8	13.5	18.8	69.0	6.8	.8	.8	3.8	1.5	2.2	1.5	4.5	311.5	6
11	111.8	.8	.8	6.0	18.8	------	------	3.0	------	.8	1.5	.8	1.5	145.8	3
12	214.5	3.0	7.5	22.8	53.3	------	3.8	15.0	.8	1.5	------	------	6.8	329.0	7
14	109.5	.8	1.5	9.8	34.5	.8	1.5	1.5	------	.8	------	------	3.0	163.7	3
16	30.0	------	.8	6.8	15.0	------	2.2	1.5	.8	------	.8	.8	------	58.7	1
18	5.2	.8	------	2.2	12.8	------	2.2	.8	------	------	------	------	------	24.0	1
20	.8	.8	.8	------	1.5	------	3.8	.8	------	------	.8	------	------	9.3	(4)
22	.8	.8	------	------	------	------	------	------	------	------	------	------	------	1.6	(4)
24	------	------	------	------	------	------	------	.8	------	------	------	------	------	.8	(4)
Total	1,464.7	855.8	978.9	190.9	429.9	375.2	299.3	44.4	26.3	26.2	71.4	27.0	166.5	4,956.5	100
Total per cent	30	17	20	4	9	8	6	1	(4)	(4)	1	1	3	------	100

[1] Computed from measurements on plots distributed over about 130 acres and totaling 13.3 acres in area. The trees are, roughly, 35 years old, and the stand is located about 3,500 feet above sea level.
[2] Largely yellow birch; a small quantity of sweet birch.
[3] Includes butternut, red oak, red maple, hophornbeam, black walnut, eastern hemlock, and pin cherry.
[4] Less than 1 per cent.

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Table 1, based on observations antedating the ravages of the chestnut blight, indicates that chestnut and black locust were the only timber trees able to compete successfully with yellow poplar on old fields. With the elimination of chestnut, other percentages would rise accordingly. Clear-cut areas that have not been cultivated almost invariably contain a greater mixture of species competing with the yellow poplar. As previously stated, the yellow poplar in these old-growth stands is mainly seedling stock.

On the North Carolina tract one area of about 50 acres contained a much larger percentage of poplar than is shown in Table 2, but this was the result of thinning and therefore was omitted as being not entirely representative of the cove and lower-slope types. It could not be determined whether fire had followed the charcoal cutting on the tract as a whole. However, according to report, a considerable number of range stock had access to this area during the time it was regenerating. Obviously, grazing was not heavy enough to destroy all poplar reproduction, but it may have been heavy enough to reduce substantially the percentage of poplar on some parts of the tract. Several coves which contained a large percentage of Ohio buckeye, and which account for the large proportion of buckeye recorded, showed evidence of having been heavily grazed. Otherwise the mixture of species which this tract contains may be considered as representative of stands well up toward the higher altitudinal limit for yellow poplar. Although poplar shows up to much less advantage here than on the tract covered by Table 1, this stand illustrates the possibility, when other conditions are favorable, of obtaining a good regeneration of yellow poplar where old-growth forests are clear cut.

SUPPLY AND DEMAND

The present status of yellow poplar and the permanence of its position in the future as an important timber species have been largely influenced by the early agricultural and industrial development within the region of its range. Yellow poplar lends itself to pioneer uses. Since the green logs float as readily as those of northern white pine, individual yellow poplars were culled out of the woods along stream banks with the pine and floated down from as far up the waterways as the early logging operations could go. This resulted in the complete elimination of isolated trees and small groups of this species from much of the land where yellow poplar could grow to the best advantage. Later, when heavier cuttings would have permitted seedlings of yellow poplar to become established, few if any trees were available to furnish the necessary supplies of seed. Where yellow poplar was not eliminated through the cutting out of all seed trees, the stands were in many instances depleted through the clearing for crop production of the more moist and fertile lands on which it grows naturally. Even very steep coves and mountain slopes suitable to yellow poplar were cleared and farmed for a few years. This short period of tillage was sufficient to prevent yellow poplar from coming back again except as seed was blown in from adjacent forests.

As a result, many acres on which yellow poplar might have come in vigorously are barren of this valuable species, and the difficulty of supplying demands for this consistently popular wood is thereby greatly increased.

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AVAILABLE SUPPLY

The wide and scattered distribution of yellow poplar makes it difficult to publish any very accurate estimate of the remaining stand. The estimate in 1920 (*13*) was 9,611,000,000 board feet. An estimate for 1931 gives 5,172,000,000 board feet lumber tally plus 19,146,000 cords (peeled).[6] It was estimated some years ago (*1, p. 176–177*) that three-quarters of the remaining stand of yellow poplar was in West Virginia, Virginia, Kentucky, Tennessee, and North Carolina. However, the report from which the 1931 figure was compiled indicates that over half of the timber stand is in the Gulf and Coastal States from Alabama to Virginia, with less than a third in the Middle Western States and the three States—West Virginia, Kentucky, and Tennessee—from which came the great bulk of the cut in earlier years. Of these remaining stands most of the virgin growth is in country which is inaccessible or very difficult to log. Much of the second growth, on the other hand, occurs in districts easily reached by rail and highway. This second growth, which is estimated to average barely 20 years of age, represents nearly two-thirds of the present total stand.

TIMBER CUT

The total annual production of yellow poplar lumber, together with the average value per thousand board feet from 1899 to 1930, is given in Table 3. A partial analysis of these annual totals is afforded by Figure 5 which compares graphically the trend of production for the three major States, Kentucky, Tennessee, and West Virginia, with the combined totals for North Carolina and Virginia, representing the two Atlantic States having a considerable share in the production of yellow poplar lumber in the past; Indiana and Ohio, the mid-Western States at one time considerable producers of yellow poplar; and Georgia, Alabama, and Mississippi, representing the southern group. The considerable falling off in the national total between 1909 and 1917 is reflected in the curves for these individual States and groups of States. Not all have recovered from this decline. While West Virginia and Tennessee have climbed back to something like an average production of 65,000,000 feet, Kentucky has reached the 20,000,000-foot level and shows no promising indication of remaining above it. Indiana and Ohio combined have sunk to even lower levels, but North Carolina and Virginia, taken as a group, compare very well with either West Virginia or Tennessee. One of the most interesting developments is shown in the curve for the combined output of Georgia, Alabama, and Mississippi. This group has increased fairly steadily in production since 1922 and shows no immediate sign of dropping off. It is considerably higher at the present time than are the two seaboard States, and the 1929 production is almost equal to that of Tennessee and West Virginia combined. This trend, due to the recent exploitation of the southern bottom-land hardwoods, has had a considerable influence on the national production figures, which show a fairly steady increase from 1921 to 1929.

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[6] United States Department of Agriculture, Forest Service. The forest situation in the United States. A special report to the timber conservation board. 46 p., illus. January, 1932. [Multigraphed.]

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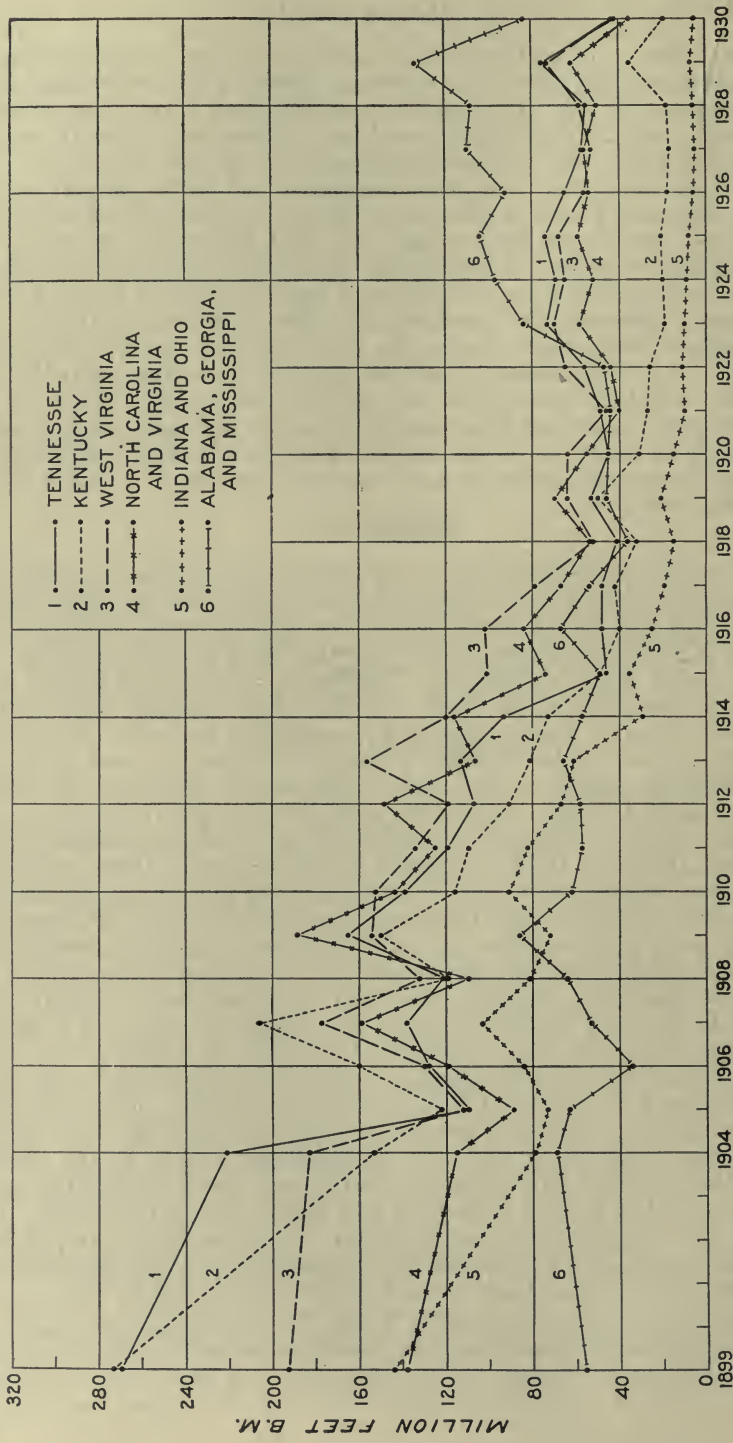

FIGURE 5.—Annual production of yellow poplar lumber, by States and groups of States of greatest past and present production, 1899 and 1904 to 1930.

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TABLE 3.—*Annual production of yellow poplar lumber, with average value per thousand feet board measure at mill, 1899 and 1904–29* [1]

Year	Quantity	Value	Year	Quantity	Value
	M ft. b. m.	*Dollars*		*M ft. b. m.*	*Dollars*
1899	1,115,242	14.03	1917	325,968	27.17
1904	853,554	18.99	1918	241,693	35.06
1905	582,748	----------	1919	328,538	41.65
1906	683,132	24.21	1920	270,407	58.87
1907	862,849	24.91	1921	235,418	37.31
1908	654,122	25.30	1922	273,971	39.18
1909	858,500	25.39	1923	353,156	51.29
1910	734,926	24.71	1924	350,727	44.38
1911	659,475	25.46	1925	375,662	43.44
1912	623,289	24.06	1926	321,579	38.63
1913	620,176	----------	1927	334,604	38.58
1914	519,221	----------	1928	327,883	40.90
1915	377,386	22.45	1929	435,953	41.66
1916	394,854	21.89	1930	257,803	35.19

[1] From (*14*) and later Forest Service compilations.

There is little likelihood that the upward trends for 1929, as shown in Figure 5, bear any promise for the future. With comparatively few old-growth stands remaining and these largely inaccessible, and with second-growth stands estimated as averaging barely 20 years, it is to be expected that production figures will fall off very materially in all States and that the total annual production of yellow poplar lumber will fall below 200,000,000 feet and average less than that.

In this connection it is of interest to note the considerable increase in the consumption of yellow poplar pulpwood since 1922, as shown in Table 4. This increase has a special significance in that a considerable portion of these totals is produced by clear cutting of poplar stands too young for timber and seed production and yet past the best sprouting age. The result is the practical denudation of such areas so far as future production of yellow poplar is concerned.

TABLE 4.—*Consumption of yellow poplar pulpwood in the production of paper, with price per cord, f. o. b. mill, 1916–30*

Year	Quantity	Price	Year	Quantity	Price	Year	Quantity	Price
	Cords	*Dollars*		*Cords*	*Dollars*		*Cords*	*Dollars*
1916	37,974	7.36	1921	43,220	16.85	1926	134,747	13.03
1917	41,155	8.97	1922	102,200	13.78	1927	131,168	13.54
1918	61,247	10.56	1923	102,781	13.94	1928	122,738	12.23
1919	72,605	15.02	1924	128,037	14.53	1929	129,697	11.41
1920	73,998	16.67	1925	145,871	13.83	1930	97,795	10.41

This drain on young stands of yellow poplar is a serious threat to the future supply. It is indeed possible that the future supplies of yellow poplar might be cut down to the point where the species would no longer be marketable except in relatively inconsiderable quantities for special uses. Such has been the fate of some other hardwoods, notably basswood. Although yellow poplar in 1929 stood fourth among hardwoods in volume of lumber cut, there is every evidence that it may fall considerably below this point before recuperative measures can be effective.

CHARACTERISTICS AND REQUIREMENTS OF THE SPECIES

Yellow poplar has maintained its place in the virgin forests through its large size, length of life, high resistance of the mature trees to injury, prolific reproduction, rapid growth in early life, and the fact that it develops a single leader and can, if this leader is destroyed,

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immediately send up a substitute leader. These advantages are, however, insufficient in many instances to counterbalance its extreme intolerance of shade. Under dense stands of beech, yellow birch, and sugar maple in the northern forests yellow poplar has no chance of establishment, and even under the lighter-crowned oaks, hickories, and chestnut yellow poplar is usually eliminated. Yet among these lighter-crowned associates, wherever sufficiently large openings occur to allow a young poplar to thrust its leader up into the light, rapid growth brings the seedling quickly into sapling and pole size and enables the tree to find a place in the crown cover, whereupon it rarely fails to hold its own.

RESPONSE TO EXTREMES OF TEMPERATURE

It is very evident that the vagaries and inconsistencies in the occurrence of yellow poplar within its range, which have already been mentioned, are rarely to be explained by anything that affects the growth of the tree in later years. Evidence shows that, where seed was plentiful, the occurrence of the tree as single individuals or in small groups in the virgin forests was governed entirely by the degree of light and moisture that was available in early years. This, however, will not explain the absence of yellow poplar on large areas of suitable soil where there is little or no serious competition from other tree growth. Nor will it explain why, up to the very limits of its reported natural range, large trees in full vigor are quite commonly found. The implication in this vigorous growth at the limits of range is quite evidently that these individual trees have by some accident passed successfully crucial stages in early growth. There are many indications in the observed behavior of the younger trees that yellow poplar in early youth not only must have adequate light and moisture, but also must be favored by climate, both in protection from extremes of temperature and in the assurance of a reasonably long growing season. In Table 5 records are presented from stations that approximate the limits of range for yellow poplar. The approximations are manifestly crude and it is regretted that no better records are available. Very roughly, the indication is that yellow poplar, for growth in marketable quantities, requires a mean annual temperature of over 48° F. and a growing season of at least 180 days.

TABLE 5.—*Weather records for selected stations near limits of range for yellow poplar* [1]

Station	Precipitation		Temperature			Average growing season
	Growing season [2]	Dormant season	Mean annual	Mean maximum	Mean minimum	
	Inches	*Inches*	*°F.*	*°F.*	*°F.*	*Days*
Albany, N. Y.	18.84	19.55	48.2	57.0	40.0	176
Buffalo, N. Y.	15.69	21.50	46.8	54.0	40.0	173
Detroit, Mich.	15.94	17.12	48.2	56.0	41.0	164
Chicago, Ill.	16.85	16.69	48.7	74.0	59.0	181
St. Louis, Mo.	19.53	20.57	55.8	64.0	48.0	200
Pine Bluff, Ark.	19.13	31.52	62.9	74.2	51.3	221
Highlands, N. C.[3]	31.50	46.70	50.0	61.0	40.0	----------

[1] Summary of climatological data from Bulletins Q and W of the Weather Bureau, U. S. Department of Agriculture, for observation periods of 20 to 86 years (*7*, *16*).
[2] May, June, July, August, and September.
[3] Selected as being near the altitudinal limit of range of yellow poplar in North Carolina.

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At its extreme southern range, yellow poplar grows only on moist sites where it is protected from extreme drying. To what degree temperature is a factor here it is impossible to judge. Other indications of the effect of climate are found in injury to the thin bark of young trees through sun scalds, which has been noted in southern Indiana, and the fact that frosts sometimes kill back the new growth. There is, however, no indication that any of the trees are killed in the dormant season by low temperatures.

SOIL-MOISTURE REQUIREMENTS

Yellow poplar has been generally characterized by observers as a tree very exacting in soil and soil-moisture requirements. The tree is nearly always found on moderately moist, well-drained soils of loose texture, but never in a thrifty condition on very dry or very wet soils. Good growth has been observed on alluvial soils bordering streams, on the dark-colored loam soils of mountain coves and ravines, on the talus slopes below cliffs and bluffs, and on well-watered gravelly soils. Sandy soils, as on the Cumberland Plateau of Tennessee, appear to be suitable only if free from excessive drying. The influence of chemical composition of soil on growth of poplar is apparently slight. In its range from the bottom lands of the coastal plains through the slopes of the Appalachian Mountains and Plateau, the tree obviously thrives on soils of many kinds of chemical composition and physical texture and grows well on both lime soils and those deficient in lime.

Favorable depth, aeration, and moisture of soils are commonly found in the heads of coves or on stream banks, which are characterized by loose, deep, dark loams well supplied with humus from the decay of abundant leaf litter. From such favorable situations, yellow poplar extends upward along the moist slopes where soils are good but less favorable. On south and west exposures, however, it is usually confined to the lower slopes. Dry site conditions are reflected in a marked reduction of growth rate and a lower density of stand. On steep hillsides yellow poplar will often exhibit a marked difference in height growth within a distance of 50 feet up or down the slope.

In the coastal-plain lowlands, as in the valley lands of Ohio, Indiana, and south through the river bottoms to Louisiana, yellow poplar occupies the better-drained alluvial or muck soils. A combination of thin soils, such as that formed by friable shales in southern Ohio, together with exposure to the south and west, causes it to give way to other species.

In the study of yellow poplar under natural conditions, it is not uncommon to find examples of a growth that is in one way or another exceptional. One such instance was found in Cecil County, Md., just northeast of Chesapeake Bay, on an old field with a northern exposure and medium slope in a Susquehanna gravel soil. An adjoining cultivated field might have been judged to be too dry for a good growth of yellow poplar, yet on the abandoned field a stand of second growth had come in, which in 31 years had attained a height of 90 feet. This stand was very dense and had the highest volume yield for its age of any second-growth stand of yellow poplar on record.

The reaction of yellow poplar to the effects of erosion is well illustrated in a badly washed field in a steep cove of Lawrence County,

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Ohio, which was planted with poplar in 1918. Part of this field was a bench adjoining other woodland, and this portion had largely retained its soil. Here, 13 years after planting, the poplar had grown to a diameter of 8 inches and a height of 35 feet. In the center of the field, however, where the soil was noticeably eroded, were trees of the same age less than 10 feet high and less than 2 inches in diameter. This difference would seem to be solely attributable to soil conditions.

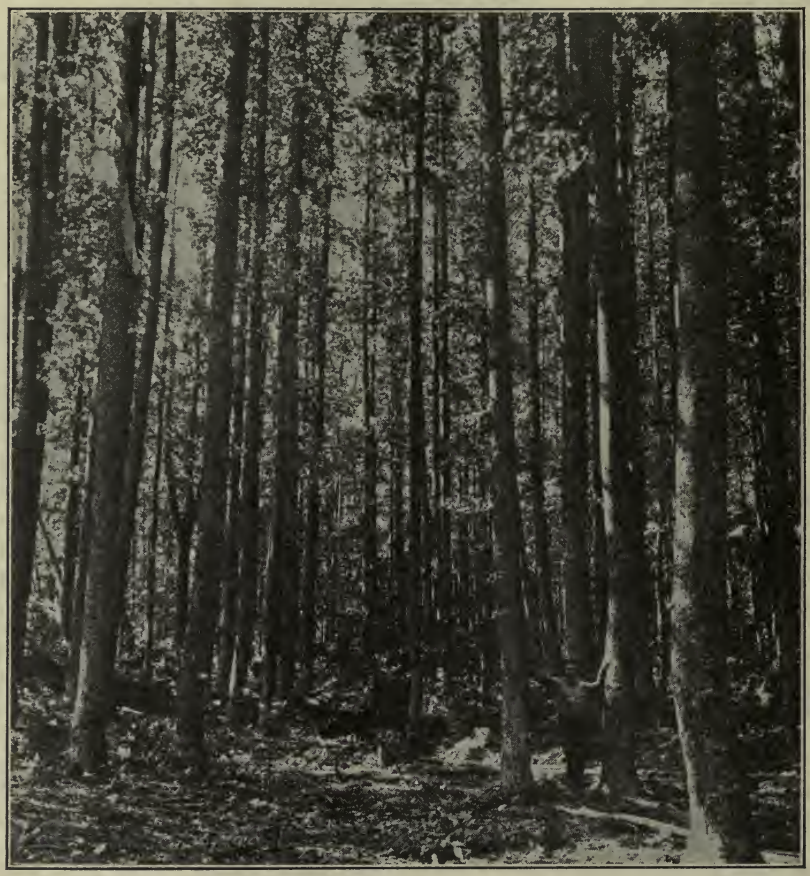

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FIGURE 6.—Poplar second growth seeded naturally into an old field, Sosebee Cove, near Blairsville, Ga. This stand showed 6,961 cubic feet of wood per acre at 48 years of age. The average dominant tree was 110 feet high

The most spectacular stand of yellow poplar seen during the study of yield in second growth was in the Sosebee Cove about 10 miles south of Blairsville, Ga. (Fig. 6.) In this abandoned field yellow poplar had seeded in naturally and had grown up into a dense 48-year-old stand in which the dominant trees were 110 feet high and the largest tree measured 26 inches in diameter. This stand grew in a region of heavy rainfall which had probably washed away much of the better topsoil during the period of cultivation; but the stand had itself reestablished good soil conditions and achieved a phenomenal growth.

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LIGHT REQUIREMENTS

Vigorous growth of yellow poplar has been found on land that would ordinarily be considered too dry, and even in places where the climate would appear to be too severe, but the one great obstacle to yellow poplar growth that is never surmounted is its intolerance of shade. Even under the oaks, hickories, and chestnut with which poplar is commonly associated, the seedlings of this species can rarely manage to persist for more than three years if the crown cover is of average density. Similarly, seedling yellow poplars which have started after a fire in a young stand are soon overtopped by the sprout growth of yellow poplar and other young hardwoods burned back by the fire. Even staghorn sumach, sassafras, and black locust may form stands too dense to allow poplar to grow up from beneath, although it is probable that the failure of yellow poplar in these instances is due partly to the competition of these light-crowned trees for water and nutrient elements, which so weakens the poplars as to make shading out an easy matter. The only shade under which yellow poplar appears to thrive is that of grass and low bushes, in old fields. Once well started in such situations, yellow poplar can survive the subsequent competition of any other seedlings of the same age.

This requirement of yellow poplar for an abundant supply of light chiefly explains many of the peculiarities of its occurrence which have already been described. Where only narrow openings were left in the crown cover of old stands by selective cutting, only occasional individual trees could push up into the light. On clear-cut areas the success of yellow poplar has depended almost entirely on the degree of sprout competition; hence abundant growth has come in only where the cutting has been made in mature timber which sprouted weakly if at all. Where younger stands are clear-cut, good yellow poplar seedling growth can follow only if the dominant sprout stand is cut back in the first or second year.

One feature of the tree's intolerance of shade which is often to the advantage of the stand is the complete and prompt dying out of all branches below the upper crown when the stand is at all dense. In dense pure stands of yellow poplar the crown may be reduced to as little as one-sixteenth of the total height of the tree. The branches not only die quickly when shaded but decay most rapidly at the point of union with the main stem, so that the limbs usually break off within the bark zone of the main stem leaving only a slight pit rather than a projecting stub. This results in the minimum blemish in the wood and consequently young poplars grown in dense stands can be cut for lumber in much smaller diameters than most species.

In even-aged stands of yellow poplar nearly all the living trees occupy a place in the upper crown level, the crown cover being of medium density. Trees which can not maintain their place in this crown cover quickly die out. When such stands are thinned, adventitious buds start out along the clean boles of the trees that are left, causing a considerable production of new branch growth commonly known as water sprouts. As the upper crown takes advantage of the increased light and spreads farther, these water sprouts die and fall off.

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NATURAL REGENERATION

Owing to the fact, already stated, that yellow poplar seedlings can not exist beyond the second or third year under the shade of the parent stand, no dependence can be placed upon advance growth to renew the stand.

In respect to sprout reproduction, yellow poplar is also somewhat at a disadvantage. Although in the case of a very young tree bending the stem or partial girdling is often sufficient to start sprout growth, stumps of trees that are not cut relatively young sprout with little vigor or not at all. Where sprouts do come in in any quantity they are subject to serious if not disastrous damage from wind and sleet, since the young stumps from which they spring decay very rapidly and afford them little support. (Fig. 7.) The sprouting ability of yellow poplar is mainly a safeguard in case a young seedling stand is destroyed by fire, or a last resort where young stands are clear-cut for pulpwood and seed is absent. If pulpwood cuttings become more intensive, as is threatened, the ability to sprout may become a much more important factor in the regeneration of yellow poplar than it is at present.

Successful reproduction of sprout yellow poplar has been observed in Pike County, Ohio, where a pure stand 28 years old was clear-cut for pulpwood in 1923. (Fig. 8.) Two years later the area was densely covered with blackberry bushes which partly overtopped the poplar sprouts. In 1929, however, a measurement on a representative ⅕-acre plot on this area recorded 269 sprouts 1 to 4 inches in diameter and about 20 feet in height. They had overtopped seedlings and sprouts of red and sugar maple, slippery elm, white ash, black locust, dogwood, and redbud. These sprouts came from stumps up to 16 inches in diameter, all of which had in the six years since cutting decayed to a mass of soft pulpy wood. Seed crops had been ample previous to cutting, but only seven yellow poplars on this area could be identified as seedlings. Seedling regeneration has little if any chance in competition with sprouts of yellow poplar and other species.

SEEDLING REPRODUCTION

Yellow poplar seed is borne annually in winged carpels about the central axis of an erect conelike fruit or strobile. The seed averages 12 to 15 per cent fertile, ranging from 5 to 30 per cent. Seeds borne at the base and apex of the fruit are usually sterile. Seed crops are heaviest on trees grown in the open and upon parts of the crown exposed to full light, such as the top of the tree and the ends of the limbs.

At maturity, the carpels become loosened in dry weather but are blown out of the cup-shaped ring of basal scales only by comparatively strong winds. The dissemination by wind is usually to a distance equal to four or five times the height at starting. Dissemination begins about the time of the leaf fall, and usually continues well into the winter.

Evidence gathered under various conditions and at different points indicates that yellow poplar seed which does not reach mineral soil may remain dormant for a year and possibly longer. Such seed has been known to germinate through the first part of the second growing

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season after its fall, but the duration of its viability beyond that time is not definitely known.

On an area of moist bottom land in Cecil County, Md., which was lightly burned in the spring of 1922, examination in September of that

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FIGURE 7.—Yellow poplar sprouts readily and vigorously, but the old stumps rot quickly. In the six years since cutting this stump of a 28-year-old tree has decayed almost entirely, leaving poor support for the sprouts

year disclosed a very dense stand of yellow poplar seedlings that had followed the fire. Where the leaf litter had been removed by the light fire, seven or eight times as many seedlings had come in as on a

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similar area on the opposite side of the small stream, where the leaf litter had not been removed. The fire was severe enough to have destroyed the seed of the fall crop of 1921 which was still mixed with the loose top layer of litter, and the assumption is therefore reasonable that practically all of this dense stand of seedlings came from an earlier crop of seed which was buried beneath the more inflammable top litter.

The disturbance of the forest litter caused by logging operations is generally sufficient to bring much of whatever dormant seed there

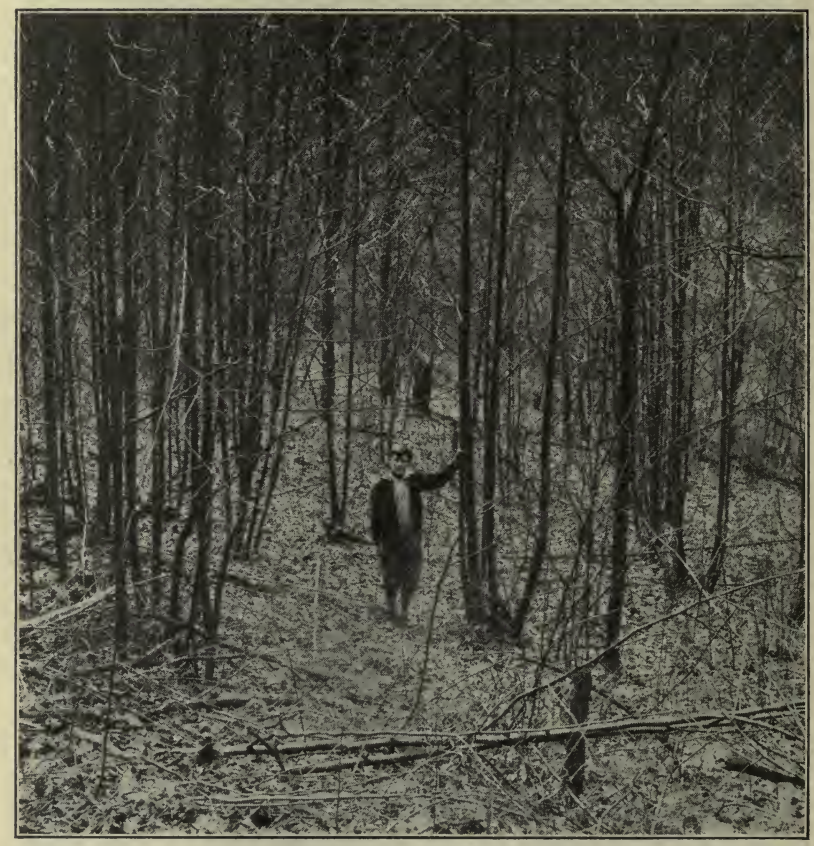

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FIGURE 8.—Poplar sprout growth which followed clean cutting in Hickson's Run, Pike County, Ohio, in 1923. This sprout yellow poplar, some of which is over 4 inches in diameter, was produced in seven growing seasons

may be into contact with the mineral soil. Also seed falling at the time of cutting can reach the soil and at the same time receive sufficient sun warmth to encourage germination. Once germination is accomplished, the seedlings must face a critical period of one to three years in which a number of different conditions must be favorable if they are to survive. The small seedlings must have protection from drying out in summer and from frost heaving in winter, but the grasses or weeds which provide this protection must cast little or no overhead shade. The seedlings must have moisture, with good drainage. They

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must have no near-by rivals in sprout growth, and seedling competitors must be of about the same age or younger.

On an area in the Pisgah National Forest occupied by second-growth red maple with scattered yellow poplar trees of seed-bearing size dominating the stand, a fire of medium severity burned a part of the bottom land along Bent Creek. Periodic examination of 150 quadrats on this area, representing four different types of treatment, brought out the record of yellow poplar seedlings shown in Table 6.

TABLE 6.—*Seedlings per acre of yellow poplar on Bent Creek bottom land partly burned in April, 1925, at times of observation in subsequent years*

Quadrats (50 square feet each)		1925	1926	1927	1929	1931		
Number	Condition					Total	New [1]	Old
	Burned:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
40	Clear cut	35,741	9,234	900	1,118	283	44	239
60	Uncut	32,636	9,467	2,381	2,714	798	667	131
	Unburned:							
24	Clear cut	2,360	1,270	73	897	544	363	181
26	Uncut	1,324	1,463	355	4,976	1,575	871	704

[1] Identified by the presence of cotyledons.

Sims (*11*) sums up the evidence from these quadrats as favoring burning after clear cutting as a means of stimulating yellow poplar regeneration. He points out that the sudden loss suffered by the clear-cut quadrats was probably due to the fact that the lush growth of ferns that came in immediately received more benefit thereon than did the poplar. A dense mat of fern roots 2 or 3 inches thick covered the whole area. In 1931 only 87 seedlings per acre more than 6 inches high were found on the burned-cleared areas and only 36 per acre on the unburned cleared. No seedlings higher than 6 inches were found on the other two. Failure here was of course due to the severe light and moisture competition of the ferns.

The worst type of cut-over land for seedling reproduction is the young pulpwood cutting, where sprouts of all species invariably get the start on yellow poplar seedlings and greatly outgrow them. Some of the best sites are abandoned fields where seed is blown in from neighboring stands, and grass and low brush form ideal protection yet give little overhead shade. Many such abandoned fields through the mountains from north Georgia to southern Pennsylvania and west into Tennessee and Kentucky have seeded naturally to yellow poplar. Next best is the clear cutting in old-growth forest, where sprout growth is feeble or lacking and the only perils are drying out and frost heaving. If these can be survived during the first year, regeneration is fairly well assured. On cuttings of mature or nearly mature second-growth saw timber, it may be necessary, as will later be shown, to reduce disastrous competition from other species by relatively inexpensive thinnings. (Fig. 9.)

On suitable old fields where no seed trees are adjacent, any yellow poplar regeneration must be started by planting.

On any site favorable for yellow poplar growth, seedlings will attain a size by the end of the third year that leaves little doubt of the successful establishment of the new stand, provided it can be protected from adventitious injury.

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SUSCEPTIBILITY TO INJURY

The agencies most likely to injure severely or to destroy a stand of yellow poplar are grazing and fire, both within the control of the owner. Until the period of settlement by the white man, yellow poplar had contended with all its natural enemies and maintained its place on the more moist, better-drained soils for hundreds of years. As the Eastern, Southern, and Middle Western States became settled, the clearing of land, the logging of merchantable trees, increase of fires, and grazing by domestic animals exerted new destructive influences upon yellow poplar.

GRAZING

Because of their succulence the twigs and smaller branches of yellow poplar are eagerly browsed by all classes of livestock in preference to

F264816

FIGURE 9.—Three-year-old yellow poplar reproduction following the cutting of a large yellow poplar on the edge of a 40-year-old stand of *Pinus virginiana*. Seedlings have come in at the rate of 100,000 to the acre

other tree species. Even where cattle are not numerous, as in the mountain regions, individual trees are damaged here and there along trails and streams, and in other places where cattle congregate. Where the cattle are numerous, and particularly where they are confined, the damage is very severe. Seedlings are grazed to the ground, small saplings are trimmed back to stubs, and large trees up to 14 feet high may be ridden down and partly destroyed.

In the mountains of Pennsylvania where deer have become very numerous, yellow poplar seedlings are often extensively destroyed by their browsing.

Within the range of yellow poplar, grazing did not become a serious factor until the day of the fenced wood lot. In the early days cattle roamed over wide areas, but as settlement increased, fencing of stock became the rule. At first, cattle were put in inclosed pastures; now

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the tendency, at least in the richer agricultural regions, is to use small inclosures not needed for cultivation as holding lots for the stock and to give the stock supplemental food. The result is that on areas where stock are so concentrated the young growth of yellow poplar is about wiped out.

FIRE DAMAGE

Yellow poplar seedlings and saplings are among the trees susceptible to fire killing because of their thin bark. (Fig. 10.) Stems up to 1 inch in diameter have little chance to escape any leaf fire hot enough to run over the dry forest floor. The damage in such cases is likely

F240214

FIGURE 10.—Yellow poplar trees 10 inches and less in diameter are very sensitive to fire injury. Fire damage is normally followed by decay

to be permanent in effect since the yellow poplar sprouts that follow the fire can not compete successfully with the sprouts of chestnut, oak, hickory, black gum, dogwood, and sourwood, as well as shrubby species that are already growing rapidly and are not seriously checked by light surface fires. Following even one such fire in a very young stand, only a few yellow poplar sprouts will be able to seize a place in the upper crown cover. A second light fire will practically eliminate young yellow poplar.

In any fire season, the nature and extent of possible damage to yellow poplars will also be determined somewhat by the maturity of

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the tree. Recent experiments at the Appalachian Forest Experiment Station indicate that the yellow poplar bark will not burn readily and that when the bark of the larger saplings becomes thick enough (say, 0.5 inch or more) to insulate the cambium adequately, yellow poplar is one of the most fire-resistant of eastern trees.

The severity of damage by fire varies not only with the kind and quantity of fuel and its rate of burning, but also with the time of year in which the fire occurs. Fires in hardwood forests feed chiefly upon leaf litter and dead herbaceous vegetation. They burn most severely where there is an accumulation of deadwood, such as slash left from a logging operation, fallen trees, stumps, or deadwood left

F18306

FIGURE 11.—Fungus fruiting body indicating decay. This fungus entered the base of a yellow poplar through a fire scar

in the tree as a result of wounding by earlier fires. Fires are most common in the spring and fall, when the hardwood trees offer no shade and the forest floor dries out most severely.

Yellow poplars in sizes between the seedling stage and 18 inches in diameter are readily wounded in proportion to the severity of the fire; but the most serious feature of this wounding is that by means of it fungi are enabled to attack the heartwood. (Fig. 11.) Hollow-butted yellow poplar trees are common in the virgin forest as the result of such fire wounds.

An example of the degree of damage which a yellow poplar stand may suffer from the combination of decay and fire wounds is afforded by a detailed study made in 1924 on 144 trees. These represented

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the complete cut on representative plots of two logging operations, one a plot of 79 trees along Cantrell Creek on the Pisgah National Forest, and the other of 65 trees about 10 miles west of Fontana, N. C. Of these trees, 94 (or 65 per cent) were diseased with wood-rotting fungi, 93 being rotted at the butt. The causal fungi were determined partly from cultures [7] but chiefly from the type of decay, as follows:

	Per cent
Armillaria mellea (Vahl.) Quel	62
Hypholoma sp	11
Polyporus sulphureus Fr	7
Polystictus hirsutus Fr	6
Polyporus fumosus Pers	4
Polyporus cerifluus Berk	3
Pleurotus ostreatus Jacq	1
Undetermined species	11

Some of these trees were attacked by more than one species of fungus, and in some cases wood partly rotted by one species was attacked and more completely destroyed by a second one. Of the 94 trees which were decayed, 59 had fire scars which had healed over, 34 had open fire scars, and 1 tree bore an open lightning scar. The ages at which different percentages of the trees in these two plots were infected were estimated as follows:

	Per cent
20 to 40 years	20
40 to 60 years	16
60 to 80 years	7
80 to 100 years	8
100 to 120 years	4
120 to 160 years	2
Undeterminable	43

The total scale of these 144 trees was 123,160 board feet (Scribner Decimal C log rule), of which 19,550 board feet, or 15.9 per cent, was deducted for decay due to fire. This deduction represented not only the actual amount figured as cull [8], but included the total volume of discarded logs which were left in the woods because of cull.

ICE DAMAGE

The greater part of the natural range of yellow poplar lies within the zone in which the formation of sleet ice is a relatively frequent occurrence. The possibility of damage by sleet is increased by the wide range of elevation characteristic of yellow poplar, which increases the chances of combination within poplar stands of the critical temperature, high humidity, and slow air movement necessary for sleet formation. The damage done by the sleet varies with the nature of the stand. Trees with a slender bole are easily broken when loaded with ice. Sprout growth inadequately supported at the base by rapidly rotting stumps is easily borne down by the weight of the sleet. Frequently trees which are not broken or prostrated by the

[7] Cultural and other determinations were made in 1923 and 1924 by E. E. Hubert and W. H. Long, of the Office of Forest Pathology, Bureau of Plant Industry.

[8] Cull was determined by the formula $\frac{\frac{1}{2}(a' \times b') + (a'' \times b'') \times L}{15}$ in which a' and b' represent the greatest and smallest diameters in inches of the decay at the smaller end of the log, and a'' and b'' represent the greatest and smallest diameters at the larger end of the log, while L represents the length of the decay in feet. This formula was adopted on the advice of Donald Bruce as giving a rough approximation of the number of board feet that would be lost in sawing the infected logs. The decay infections studied were in most cases approximately conical. For logs showing decay only in one end, a' and b' were considered as zero. The deduction for decay, like the total scale, was figured to the nearest 10 board feet, anything less than 5 board feet being ignored.

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ice load are so bent out of position as to be quickly suppressed thereafter, or so broken in the top or stripped of branches as to lose out at once in the struggle for crown dominance. If the ice-injured tree, either broken or bent, is not immediately dominated by other trees in the vicinity, it is very likely to be infected with fungus at the point of injury. Instances of such forms of ice damage in yellow poplar stands 25 years old or older have been observed at Cranberry, N. C., on the slopes of Thunder Hill on the Natural Bridge National Forest in Virginia, in the Iron Mountains in Wythe County, Va., and near Berea, Ky.

Stands which have grown too densely are often subject to severe ice injury after thinning because of the lack of wanted support from adjoining trees.

LOSS FROM DISEASE [9]

The wood-rotting fungi that attack the heartwood usually enter through fire scars or other wounds at an early age of the tree, sometimes as early as the fifth year. The decay caused does not usually, however, extend more than 8 to 20 feet upward. The most common type of decay is a soft, spongy, white or gray pocket rot of both sapwood and heartwood, caused by the shoestring-forming fungus, *Armillaria mellea* (Vahl.) Quel. This fungus dissolves the wood in the region of the medullary rays, leaving irregular cavities or pockets, and occasionally attacks the roots. Less frequently present are a soft dark-brown or black heart rot caused by *Hypholoma* sp.; a honeycomb pocket rot of heartwood caused by *Polyporus cerifluus* Berk.; and a dark gray, brown, or almost black butt rot caused by *Trametes malicola* B. and C. Less frequent butt rots are caused by the following species: *Polyporus sulphureus* Fr., which causes a brown cuboidal rot; *P. fumosus* Pers., a white-mottled, yellow rot; *Fomes applanatus* (Pers.) Wallr., a white-mottled, cream-white rot; *Ganoderma curtisii* (Berk.) Murr., or a species similar in action, a white stringy pocket rot; and *Pleurotus ostreatus* Jacq., a white rot. The sapwood, when killed, is quickly attacked by a number of species, some of which extend their action to the heartwood. The most common are the following: *Irpex millis* B and C., *Polystictus hirsutus* Fr., *P. versicolor* Fr., and *Pleurotus ostreatus*, all of which cause white rots; *Polyporus fumosus* Pers., a white-mottled yellow rot; and *Fomes applanatus*.

Several parasitic species of fungi attack the leaves, though without serious effect. The most common of these is *Gloeosporium liriodendri* E. and E. Others are species of Asterina, Cercospora, Cylindrosporium, Phyllosticta, Ramularia, and Sphaerella. Two species of mildew, *Erysiphe liriodendri* Schw. and *Phyllactinia suffulta* (Reb.) Sacc., occasionally attack the leaves of sprouts and young seedlings. If these attacks begin early in the growing season they can cause considerable injury. Fungi, mostly low in parasitism, that attack and kill the limbs and twigs of young crowded and suppressed trees, especially the lower limb and any others of low vitality, include *Creonectria coccinea* (Pers.) Seaver, *Diplodia liriodendri* (Peck), *Myxosporium coloratum* (Peck) Sacc., and *Leptosphaeria stictoides* (B. and C.) Sacc.

[9] Prepared from information furnished by George G. Hedgcock, Senior Pathologist, Division of Forest Pathology, Bureau of Plant Industry.

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Yellow poplar logs, especially when cut in the warmer seasons, are subject to rapid deterioration, because of the attack of wood-staining fungi which feed largely on the starch and sugars in the green sapwood and penetrate deeply while the wood is moist. The commonest and most rapid staining species is *Ceratostomella pluriannulata* Hedgc. Other wood-staining species common in yellow poplar logs and boards are *C. capillifera* Hedgc., *Graphium rigidum* (Pers.) Sacc., and *Graphium* sp. The deterioration in grade resulting from staining is frequently great, owing to the large proportion of sapwood. Prompt utilization of logs will reduce stain losses.

DAMAGE BY INSECTS [10]

The yellow poplar has few insect enemies, and these seldom kill the tree. The most injurious is the Columbian timber beetle, *Corthylus columbianus* Hopk. (one of the ambrosia beetles). Holes bored by this insect in the sapwood of the trunks of living saplings and older trees become permanent defects. Staining fungi attack the wood about these holes and cause blue or greenish streaks that sometimes extend for several feet, producing an effect known as "calico poplar." In some localities timber is much reduced in value by this defect, which is apparently most common on wet soils in the coast region. Hopkins (*8*) finds the attacks of this insect on the decline. There is no known preventive or remedy.

The tuliptree soft scale, *Toumeyella liriodendri* Gmel., may sometimes be found in great clusters on the bark of branches. Although in heavy infestations branches sicken and die, the damage is not usually very serious. Undersides of leaves are often infested by an aphid, *Macrosiphum liriodendri* Mon., that feeds by sucking juices. These insects seldom appear in great numbers but when abundant cause paling and early falling of the foliage. The bark is sometimes inhabited by the boring caterpillar of a moth, *Euzophera ostricolorella* Hulst. Circular spots on the leaves about one-quarter inch in diameter and colored yellow or greenish and brown indicate the presence of the maggot of a small fly, *Cecidomyia liriodendri* O. S. The caterpillar of a moth, *Polychrosis liriodendrana* Kearfott, builds a small web on the underside of the leaf, usually near the midrib, and skeletonizes part of the leaf, folding the injured portion somewhat. Damage to forest stands is, however, negligible.

GROWTH AND YIELD

As previously intimated, the best growth rate of yellow poplar is ordinarily obtained on old fields which are characterized by a moist but well-drained soil, where the possibility of sprout growth has been removed by years of cultivation and grass and low brush species are growing not too densely. Few other hardwoods display a vigor equal to that of yellow poplar under such circumstances.

Characteristics of growth already mentioned have a definite effect on the yield of yellow poplar. Also more intensive management of yellow poplar stands could salvage many trees that are now killed by shading, and this would increase considerably the total volume harvested. Yellow poplar stands thin out severely as they increase in age.

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[10] From information furnished by William Middleton, Entomologist, Division of Forest Insects, Bureau of Entomology.

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HEIGHT GROWTH

Height growth of yellow poplar seedlings during the first year will range from a meager 2 or 3 inches to the 15-inch mark attained by seedlings on the best sites. The height reached depends upon the time of germination, the density of shade, and the moisture available in the surface soil. The smaller seedlings have a chance of final success only if there is sufficient light to encourage the single leader to

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FIGURE 12.—A 55-year stand of yellow poplar on a good site (elevation 2,700 feet) in northern Georgia in which heights range generally from 100 to 140 feet

shoot up and attain a position of dominance before light is shut off by the spreading crowns of larger individuals. Seedlings which grow only 2 or 3 inches during the first year are very likely to be heaved out by the frost, killed by short periods of drouth, or bent over and smothered by leaf litter.

Under full light the most rapid height growth of the seedlings begins in the second year. It is not uncommon for yellow poplar to reach 10 to 18 feet by the end of the fifth year. In one instance on a

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cut-over old-growth area in the Smoky Mountain district, yellow poplar trees, apparently of seedling origin, made the unusual growth of 50 feet in 11 years.

Yellow poplar sprouts have an even more vigorous growth and in this respect exceed all other associated species except chestnut, black locust, silverbell, and sourwood. If not interfered with by grazing, yellow poplar sprouts will successfully take and hold their place in the dominant crown cover of any second-growth sprout stand. The only dangerous competitor is the chestnut. At present the chestnut blight tends to wipe out this competition.

In the early years yellow poplar sprouts definitely outdistance yellow poplar seedlings on equivalent sites. However, no differences in the later growth rates of sprout and seedling poplar trees have been found, except where two or more sprouts from the same stump have crowded each other and reduced the growth rate of all members of the group.

On good sites, mature yellow poplar attains a height of 140 to 160 feet. Recent measurements of a 55-year old stand in the Cherokee National Forest (Ga.), gave the average range of heights as 100 to 140 feet, with at least one tree well over 150 feet. (Fig. 12.) Heights of over 190 feet have been reported, but not thoroughly substantiated. One old-growth tree on Reems Creek, about 15 miles from Asheville, N. C., shown in Figure 13, measured 28.7 feet in circumference and 144 feet in height and may once have been of even greater height.

Taking 50 years as the standard age for the measurement of site quality by height growth (*5*), a height of 110 to 120 feet is considered characteristic of the best site quality, whereas 60 to 70 feet indicates the poorest. Some of the best stands measured averaged 110 feet in dominant-tree heights in 48 years, 92 feet in 26 years, and 50 feet in 11 years.

FIGURE 13.—An old-growth yellow poplar on Reems Creek, near Asheville, N. C. This tree was measured early in 1932 and was found to have a breast-high circumference of 28.7 feet, a height to base of main crown of 83 feet, and a total present height of 144 feet.

DIAMETER GROWTH

The rate of diameter growth of yellow poplar is determined by the size of the crown formed and retained by the tree. If a goodly portion of the total height of the tree is occupied by the crown, the tree will grow rapidly in diameter, but the bole will taper very sharply

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within the crown. Trees of this species grown in the open stands on a good site often reach 15 inches in diameter at breast height in 30 years and make equivalent growth at other ages. If the same trees had been restricted by growth in dense stands, they would have made a much smaller diameter growth, but the boles of the trees would have been more cylindrical in form and freer from knots. The average diameters of all trees 5 inches and more d. b. h.[11] are shown in the Appendix (Table 17) for even-aged stands from 10 to 50 years of age and for the full range of site-index classes. The diameters shown in the table for ages up to 25 years are representative of average diameters attained by dominant trees, but those shown from 25 to 50 years are lower than may be expected in the dominant stand, since

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FIGURE 14.—Crown development in a dense, 90-foot stand of yellow poplar near Cranberry, N. C. Natural pruning of limbs has materially reduced the crowns; swaying of the boles will now result in whipping off the leaves and in checking branch growth

trees from the codominant and intermediate classes are included in these age groups.

Where the crown cover of a stand has been completely closed for a decade or more the trees will be found so severely crowded that diameter growth has been checked, even though the stand is still young. In well-stocked cove stands this slowing down of diameter growth may be expected about the twentieth year and, if the stand is not thinned, the crowding will continue until the trees are seriously retarded and have lost the power to recover promptly the early growth rate. This is because in such dense stands the lower part of the crown is shaded out. Where this condition has existed until the crowns are reduced to one-sixth or less of the total height of the

[11] D. b. h. = diameter breast high.

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tree, a further reduction will follow in area of crown because of the swaying of the slender boles in the wind, whereby leaves are whipped off and branch growth is checked. (Fig. 14.) Where this occurs, stand density is materially reduced and tree species more tolerant of shade are encouraged to grow up and crowd out the yellow poplar.

While there might be some question whether any of the stands examined so far could be called overstocked, certainly the majority of the dense yellow poplar stands examined show a marked retardation of diameter growth at about 25 years of age and have little possibility of resuming their normal rate of growth unless thinning operations make possible a prompt recovery of full crown development. An example of what might be termed overstocking is afforded by a natural stand of yellow poplar, 38 years old, located in a north-facing cove in southeastern Ross County, Ohio, which at the time of examination had a total basal area 25 per cent greater than the values shown in the yield table (Table 16) for the same site and age. During the drougth of 1930, 33 per cent of the trees died. This loss, which was all from the subordinate stand, 8 inches or less in diameter, comprising 15 per cent of the total basal area, constituted a sufficient reduction to bring the stand down very close to yield-table values. This is reasonable evidence of overcrowding, and is a very good indication of the demand that this species makes for soil moisture.

From records of 413 trees grown in old-growth cove forests of North Carolina, Tennessee, and West Virginia, the following indication of average growth rate was determined:

Years	D. b. h. (inches)
50	9
100	17
150	23
200	27

A comparison of these diameters with similar measurements in pure second-growth stands makes it clear that these yellow poplars must have been greatly impeded in growth by adjacent trees, especially at the time when they should have been making their most rapid growth.

FORM

The straightness of bole in yellow poplar, the consistency with which it maintains a single stem, the clear length of bole, and the uniformity of taper in the well-grown tree are truly remarkable among the hardwoods of the region. Studies of forest-grown yellow poplar in several States [12] indicate that the clear length of such trees is about 50 per cent of the total height for sizes from 10 to 15 inches in diameter. Trees from different regions and sites have relatively little variation in the actual clear length for any one diameter class. For the larger trees, 24 inches d. b. h. and more, comparatively uniform average clear length was found for trees of a single diameter class, even though the records included older, slower growing trees from poorer sites, and young, vigorous trees of equal diameter from the best sites.

The bole is tapering in young trees, but as the crown is reduced by shading it becomes more cylindrical. In early life a certain

[12] The figures here quoted are from tables prepared by Walter Mulford, G. M. Homans, and F. E. Olmsted, of the Forest Service, about 1904.

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degree of crowding is desirable to reduce the length of the crown; but if this crowding is not eliminated in time to preserve ample crown length, the return to satisfactory growth rate will be seriously retarded.

VOLUME AND YIELD TABLES

VOLUME

Tables 13–16 give the average volumes of second-growth yellow poplar trees of different sizes. The volumes are in terms of total cubic feet (Table 13), merchantable cubic feet (Table 14), board feet by the Scribner log rule (Table 15), and board feet by the International log rule (Table 16). These tables were computed from taper diagrams (*4*). The volumes were checked against values obtained by scaling the original taper diagrams for each height and diameter class. Tables 11 and 12 give the board foot (Scribner) volumes of yellow poplar trees over 100 years old. They are based on other measurements and other sets of taper curves than those used for Tables 13–16.

These volume tables are applicable to any average stand of second-growth yellow poplar of reasonable density, or in the measurement of volume of individual poplar trees grown in combination with other hardwood species of approximately the same size. Volume for open-grown yellow poplar trees will be lower than the average value shown in the table for any given height or diameter. The narrow range of form found in computation of the data used in the construction of these volume tables makes unnecessary the preparation of separate form-class tables for the species.

YIELDS

The yield-table values presented in Table 17 are normal values; they have been computed from 89 plots scattered well over the range of the species and representing the best stocked areas that could be found. Apparently they represent stands that have been well stocked throughout their life, and none of them was thinned or improved in any way prior to measurement. In obtaining plot measurements all acreage was horizontally measured; lines were run in such a way as to avoid selection so far as possible, except with regard to stocking of the area as a whole. No plot was discarded because it was overstocked. Diameters were taken largely with the diameter tape, heights with an Abney level and tape, and age by use of an increment borer or, wherever possible, by observation of cut timber.

Yield plots were computed by the use of the accompanying volume tables applied directly to the tally record. Basal area and numbers of trees were also obtained by direct computation from the tally sheets and were later converted to the acre basis. The curves of height on age used for the determination of site were made up from the dominant sample trees obtained upon the plots, further supported by other determinations of height-age on individual dominant trees. Plots were assigned to their respective sites as indicated by their height at a given age according to the height-age diagrams. Only plots located in a given site, according to site index, were used in computing yields for that site. Yields for several sites were then correlated.

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The use of 50 years as a basis for site index was necessary since older stands were not available to raise the age basis to 100 years. Height-age curves are still rising sharply at 50 years, and a new site index based upon older stands should be computed when stands become available for this purpose.

COMPARISON WITH YIELDS OF OTHER SPECIES

Differences in standards of utilization and measurement render it impossible to make an exact comparison between yellow poplar yields and those of other species of equally rapid growth. Approximate comparisons, however, indicate that yellow poplar ranks well. Medium site quality for yellow poplar, indicated by a height of 90 feet at 50 years, produces a yield of 24,400 board feet per acre measured by the International (⅛-inch) rule, or 4,480 cubic feet per acre of felled wood exclusive of stump and top. At the same age and on a similar site, Douglas fir (*10*) yields 31,400 board feet, or 5,690 cubic feet. Values for Douglas fir include only trees 7 inches in diameter and larger, whereas the yellow poplar tables include trees 5 inches, but this is of small importance since, at age 50, 5-inch yellow poplar trees would be eliminated and there would be few under 10 inches, whereas Douglas fir would retain all trees of the 7-inch class. The more rapid growth of the larger yellow poplar trees in early life is shown by yields at 30 years of 2,300 cubic feet, as against 1,500 for Douglas fir.

Yellow poplar compares equally well with the rapid-growing loblolly pine (*15*) which yields 5,300 cubic feet per acre of felled wood for all trees 4 inches and larger at 50 years, especially when this yield, which includes stump and top, is reduced by 2.5 per cent, to 5,168 cubic feet, to make it comparable with the yellow poplar yield.

Both Douglas fir and loblolly pine are recognized leaders in production in the regions in which they grow. Both are better able to grow under shade than yellow poplar and consequently can maintain a greater density of stand.

APPLICATION OF YIELD TABLE

The yield table given in the Appendix may be used not only to estimate the present volume of the yellow poplar stand at any given age but also to predict approximately the volume to be expected at any future time. It is necessary to know only the age, site class, and degree of stocking of any stand to which these tables are applied. Age may be determined by a ring count on cut trees or from cores bored in standing trees. Site class may be determined by comparing the average height of the dominant trees and the age of the stand with those given in the site-index table of heights at various ages. Height-age curves may also be constructed for this purpose.

Density of stocking is best expressed by the volume per acre of the stand, but this determination involves a rather laborious set of measurements and computations. On the other hand the attempt to judge density of stocking by eye will seldom result in a wholly dependable appraisal. A method that is both relatively simple and reasonably accurate is that of comparing the total basal area in square feet per acre on any stand, computed from diameters taken at breast height, with that given in the tables for stands of the same age and

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site class (*15*). Tabulated yields may then be corrected proportionally to the percentage of deviation of the basal area for the stand from that shown in the table. Where yield predictions are made, especially for long periods in advance, allowance may possibly be made for a tendency of understocked stands to become more fully stocked as they grow older and therefore to approach the values given in the table.

MANAGEMENT

Several indications have already been given of the possibilities of increasing yellow poplar yields by thinning and by improved methods of cutting, and occasionally by the judicious planting of areas that would otherwise be greatly understocked or nonproductive. Of the desirability of extending the productive areas of yellow poplar there is obviously no question. Its rapidity of growth, and the adaptability of the wood to many uses—from substitution for softwood lumber, through a variety of secondary products for which it is perhaps better fitted than most other woods, down to its very profitable utilization for pulpwood, excelsior, and similar products—will keep it in demand so long as it is available in marketable quantities. If the point is reached, however, where yellow poplar can no longer be profitably marketed, the wood-using public will turn to substitutes, and yellow poplar, like other woods that have gone through this same cycle, may no longer be in demand even when the maturity of new growth renders it available. The yellow poplar saw timber still remaining, together with the new growth, is insufficient to maintain the present cut. At the same time, any serious and protracted reduction in the cut may fall so far below the demand for the wood as to result in a loss of market. It is desirable, therefore, that the remaining and future supplies of yellow poplar be so amplified that production in sufficient quantities may be stabilized.

The development of an adequate growing stock should be a primary principle in forest management. In the management of yellow poplar, the necessity of preserving seed trees, the ample supply of seed when these are available, the difficulty of sprout competition on young-growth cut-over areas, the utter failure of yellow poplar saplings unless they are able to establish themselves in a dominant position in the crown cover, and the tendency of young even-aged stands on good sites to become overcrowded, are some of the conditions that must be taken into account in determining not olny cutting practice but also the subsequent care of cut-over areas.

The growing interest in yellow poplar as a source of pulpwood has dictated a policy of cutting out young poplar from the woods and of clear-cutting young stands that is in effect very short-sighted, since it is a sure way to destroy all chance of future crops of this valuable species. Cutting young trees from mixed woods of course removes all possibility of yellow poplar seeding in the stand in the future. The clear cutting of very young stands involves at best a gradual shrinkage of the areas of poplar growth and in many instances brings about the elimination of yellow poplar, since the sprout growth that follows, as has been explained, is very liable to succumb before the new stand has become firmly established. The early harvest of yellow poplar results from the demand for an early cash return and a disregard of the rapid increase in value of these trees as they increase in size. Even

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though yellow poplar pulpwood crops may prove profitable, the periodic cost of replanting which is necessitated thereby makes the holding of these stands to something nearer saw-timber size a much more profitable policy in the long run.

However, pulp mills offer a market for small-sized trees such as are removed in thinning, and such utilization is entirely compatible with good forest management. Since the demand for poplar pulpwood will undoubtedly continue in certain sections, this market indicates the desirability of increasing the acreage of yellow poplar and the possiblities of profitable intensive management.

CUTTING PRACTICE

OLD-GROWTH STANDS

As already explained, yellow poplar seedlings come in very readily and with good success following a heavy cutting of old-growth stands. Although there is considerable evidence to show that at least partial regeneration can come from the seed of the previous year or years that is lying dormant in the leaf litter on the forest floor, this dormant seed can never be depended upon to produce well stocked stands of seedlings. It is imperative that seed trees be left standing to supply seed for the whole area.

Seed trees should be selected for their location with respect to prevailing winds and slope; favorable sites are at the heads of coves or on slopes where their elevation will permit the most effective distribution of seed. Yellow poplar trees which are still in a stage of vigorous growth may be retained as seed trees without loss if the indications are that their stumpage value will increase rather than lessen in the course of time.

Since the rooting habit of yellow poplar on the moist soils where it most frequently occurs makes it very susceptible to windthrow, seed trees should be left in sheltered positions as far as possible.

The method of logging has no appreciable effect upon the regeneration of yellow poplar save in the matter of slash disposal. Logging in cove sites, as practiced at present, leaves the branches and tops, or "slash," collected in windrows or piles, with the spaces between very much torn up by travel of men and draft animals. This disturbance of the leaf litter is favorable to poplar regeneration, but the dense piles of brush tend to prevent the establishment of seedlings. Slash unburned should, therefore, be scattered widely so that it will offer as little interference as possible to the incoming seedlings.

Piling and burning slash furnishes some protection against subsequent severe fires, but the spots covered by the piles will remain barren and require reseeding after the slash burning. If protection of the area from later fires can be attained in any other way, piling and burning slash is probably not worth while. Complete protection must be secured, however, since even light fires are fatal to poplar reproduction. Fires which run over logged areas several years after the cutting are most destructive to poplar regeneration, and the subsequent sprouting of other species tends to eliminate yellow poplar from the stand.

SECOND GROWTH

Characteristics of growth already discussed force the conclusion—failing sufficient opportunity as yet to try out experimental methods of cutting—that second-growth stands of saw-timber size must have

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the same method of treatment as virgin stands, namely, a heavy cutting with seed trees left in advantageous positions. In second growth, however, this treatment must be supplemented by measures effective in reducing competition from the sprouting of vigorous young hardwoods of other species, against which, as has been shown, seedlings can not hold their own. The greater the proportion of other hardwoods the greater the necessity for ridding the stand of this sprout growth of such species as black locust, chestnut, slippery elm, bitternut hickory, dogwood, sourwood, and silverbell, which is certain to come in so vigorously as to overtop and kill the yellow poplar seedlings. This competing growth can, of course, be cut back after the stand is cut, but this method must be well-timed to be effective. A more certain and probably less expensive method is to accomplish the elimination of competing sprout growth before the stand is cut, by combining this cleaning operation with the thinning practice described in the next section, which should be a definite part of the management of every second-growth poplar stand.

It does not seem advisable in second-growth poplar to clear-cut the stand and depend solely on poplar sprouts for reproduction. Sprouting of yellow poplar is sufficiently vigorous, when the stand is young, to overcome most other sprout growth, but dependence on sprout growth following cutting is undesirable for a number of reasons that have already been given, the most important of which is that this will involve a reduction or at best no extension of the growing stock on the area and no opportunity to seed in adjoining open areas.

THINNING

It has been shown that pure stands of yellow poplar slow down in diameter growth at a very early age. Fairly dense growth for the first few years is beneficial in that it assists the tree to develop a tall slender bole with the lower part of the trunk clear of branches. When this has been attained thinning is needful to avoid excessive restriction of crown and consequent loss in wood production. Thinning should begin as soon as a profitable return can be obtained from the thinning operation and its aim should be to retain in the reserved trees a crown length equal to at least one-third of the height of the tree. Dominant trees of good form with well-balanced crowns should be selected for the final saw-timber crop. Trees of subordinate crown classes should always be removed, since little can be expected from them in wood production and they will eventually be killed out. The operation should not leave the stand too open on the windward side, nor so open within the stand as to encourage excessive water sprouting on the part of the dominant trees. But no effort should be made otherwise to preserve those spindling, intermediate trees which are ordinarily the ones most damaged by sleet or ice. Where a pulpwood market is available, thinning can be made profitable as early as the twentieth year. For the best timber production thinnings should be repeated whenever there is evidence of overcrowding.

As pointed out in the previous section, thinning or cleaning in mixed stands is essential to remove or greatly reduce the sprout growth of inferior species that will otherwise choke seedling regeneration of yellow poplar following cutting.

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ARTIFICIAL REPRODUCTION

The increasing acreage of abandoned crop land is adding annually to the large aggregate area suitable for the production of yellow poplar. This aggregate includes not only old fields but also much cut-over land that because of fire or grazing or lack of seed trees is likely to be seized by undesirable trees and shrubs. Almost any moist, well-drained site within its range is suitable for yellow poplar—even very steep slopes if the soils do not dry or wash excessively, or land which is infrequently flooded if the soil remains loose when it dries.

Whether sowing seed or planting with nursery-grown stock is the more successful method of reproducing yellow poplar on such lands can not be stated categorically. Experience with other species favors planting over sowing as a general rule. One recent experiment (*9*) with yellow poplar showed results definitely unfavorable to sowing.

SOWING

The labor cost of sowing yellow poplar seed in the field is high and will approximate that of planting for the same area. Furthermore, because of the uncertainty of weather conditions and the very serious results of unfavorable weather in seeding operations, the percentage of success is likely to be much lower than for planting. Unless some vegetation grows up around the seedlings, they may be frost-heaved during the first winter following germination. If the competing vegetation is too dense, seedlings may be smothered. For these and other reasons seeding is hardly feasible except in carefully selected places.

If the establishment of yellow poplar by sowing seed is attempted, small spots 15 to 18 inches across should be prepared, from which the sod or other vegetation has been removed. Considering the very low germination percentage of yellow poplar, even when the seed has been kept moist over winter by stratifications, 60 to 80 seeds per spot are no more than sufficient to insure establishment. The seed should be covered to a depth of about one-fourth inch.

PLANTING

Planting yellow poplar is not only practicable on the better soils but can be done quite cheaply if reasonable care is taken. It may be employed on very open burned areas or in favorable locations in cut-over old growth, as well as in suitable old fields, but it will not ordinarily succeed where a young hardwood forest has just been cut away or burned, for the vigorous sprout growth that follows immediately will suppress the planted poplar seedlings.

Where sizable openings occur between stumps or sprouts on woodlands recently cut or burned, it may be feasible to supplement the growing stock by planting yellow poplar seedlings. This may involve subsequent cleaning out of competing sprout growth in another three or five years; yet if the planting is carefully done and confined to the larger openings, the cost of such cleanings should not be excessive.

The results of the spread of the chestnut blight furnish an opportunity for yellow poplar planting. The lower chestnut slopes on northerly exposures will probably revert largely to oak after the death of the chestnut. These stands are likely, however, to be poorly

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stocked for a number of years, and if yellow poplar trees can be established in small plantations to serve as centers of seed distribution, they will bear seed early enough to restock some of the land on which the chestnut has died out. Planting should not be undertaken on land naturally adapted to the growth of chestnut oak, black oak, scarlet oak, or pitch pine, because such land is usually too dry. Yellow poplar will not thrive as well as will shortleaf pine in the post-oak type on the piedmont plateau. It will do well, however, on land suited to white oak, in the beech, birch, and maple forests, on the heavier soils normally occupied by northern white pine in the lower edge of the beech, birch, and maple forests, and on such heavy soils as are occupied by red oak, white ash, Ohio buckeye, and basswood. It should not be planted on poorly drained soils or on land along streams subject to frequent or protracted overflows.

A word of caution should be added against the notion that promiscuous planting of yellow poplar or, for that matter, any other equally exacting species, will be successful on all abandoned fields. Investigations in forest soils undertaken recently by the Central States Forest Experiment Station are already producing evidence tending to invalidate the rather general belief that since soils were once capable of growing good species, as exemplified by remaining adjacent stands, they are still good enough for such species as walnut, poplar, etc. The present indication is that there has been a tremendous loss of fertility, porosity, and moisture capacity in abandoned fields. Apparently there are many such fields that are no longer capable of growing good hardwoods successfully, at least until they have been improved for a time by a cover of pine, locust, and similar species.

NURSERY PRACTICE

Some States have forest nurseries which are able to supply yellow poplar planting stock as demanded. Where such a source is not readily available and other conditions are favorable, it may be desirable to raise from seed the stock needed.

Yellow poplar seed can be collected most easily and at lowest cost following a logging operation that occurs in wet weather or immediately following wet weather in early fall. At such times the mature fruit closes tightly and will carry the seeds to the ground without scattering. Once the tops are down, the seeds are held in place even when dry by the ring of basal scales and the central stalk of the fruit and can be collected at a cost of 15 to 20 cents a pound. Seed can be purchased from seed dealers at prices varying from 40 cents to $1 a pound.

Seed collections should be made as soon as possible after the seeds are ripe in the autumn, since yellow poplar seeds quickly lose their germinating power if allowed to become dry. For the same reason it is necessary either to plant these seeds in the fall of the year or to stratify them in moist sand for cold storage through the winter. Seeds that are stored dry during the winter will not only have a low germination percentage, but will usually fail to germinate for a whole year after sowing. Nursery sowing can probably best be done in the fall, if the beds are mulched with dry leaves or rye straw to prevent drying out during the winter. This mulch should be removed before germination is expected. If sowing is delayed until

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the spring, it will be necessary to stratify the seeds over winter in moist sand in such a way that they can be separated by screening when the nursery bed is prepared for planting. It is, of course, necessary to make sure that the sand is kept moist through the winter.

On moist, fertile land yellow poplar seedlings suitable for field planting can be grown easily and cheaply with no other care than weeding and cultivation.

Poplar seed ranges from 10,000 to 18,000 to the pound (*12*) and averages about 15,000 seeds, of which only 5 to 30 per cent will be fertile, the lower figure representing carelessly collected or dry-stored seed. Broadcast sowing in beds is advantageous when only a small number of trees are to be grown, but is not so desirable in larger projects, since the sensitiveness of the seedlings to shading and lack of moisture places them at a disadvantage in the crowded broadcast bed. Furthermore, seedlings grown in drills tend to produce sturdier planting stock with the same amount of shading and watering. Seed should be sown in drills at the rate of 50 to 75 to the linear foot, and the drills should be 8 to 12 inches apart (*9*). Mulching, as already stated, is essential.

Since planting the seedlings at the end of the first year saves nursery and planting costs, the stock should reach one-half to 1 foot in height in this first season. For this reason, it is desirable that the soil should be rich and otherwise similar to that found on the best natural poplar site. Stock should not be encouraged to grow higher than 1.5 feet before planting.

FIELD PLANTING

Experience has shown that in the Ohio Valley as well as in the southern Appalachians yellow poplar seedlings can be removed from the nursery and planted most successfully in March or early April just before the spring growth takes place. Spring planting has now largely superseded the earlier practice of fall planting. Trees which are planted in the fall are less able to withstand winter killing than if left rooted in the nursery. Planting too early in the spring must be avoided. Much of the failure in poplar planting is doubtless due to too long a period elapsing between the planting and the beginning of the new season's growth, permitting injuries to the fleshy root system to result in the decay of the roots and subsequent loss of the planting stock. If in spring planting it is found that the growth of the stock has started before the field work is accomplished, the top may be cut back to the last well-formed bud, and a new leader will develop. Yellow poplar has an advantage over conifer planting stock in that the terminal bud need not be preserved.

No special tool is needed for planting so long as the hole is made deep enough and broad enough for the root system. No preparation of the ground is needed except the clearing of vegetation immediately surrounding the place for the tree. Trees should be set erect and as deep in the ground as they were in the nursery. The roots should be straight and firmly packed with soil. Care should be exercised in handling the planting stock to prevent the drying out of the fine root hairs and small, fibrous roots, since these are easily injured by short periods of exposure to the sun and dry winds.

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The correct spacing depends on the purposes of the planter. Close planting will cause side limbs to die and will result in trees free from knots; but unless an adequate system of subsequent thinnings is definitely planned, it will be safer to insure more rapid growth by giving plenty of room to each tree. As a general practice, it is not advisable to plant yellow poplar closer than 7 by 7 feet or wider than 10 by 10 feet. If the spacing is 7 by 7, it will take 890 trees to plant an acre; if 10 by 10, it will take 435 trees.

PURE VERSUS MIXED PLANTATIONS

Pure plantations of yellow poplar can very possibly be grown to maturity successfully. Observations this far made disclose an apparent tendency on the part of pure stands to stagnate after reaching pulpwood size, but this difficulty might well be obviated by making a pulpwood cutting by way of a first thinning operation. An auxiliary pulpwood crop may in many instances pay the cost of planting and management while the crop of saw timber is being grown. Ordinarily a mixed plantation is insurance against complete destruction by insects or other agencies which might kill or damage all trees of a single species; but, as has already been shown, yellow poplar seldom suffers serious damage from insects or disease, and there is no reason to anticipate serious trouble with a pure stand on this score. The dry leaves of yellow poplar deteriorate so rapidly that a pure stand of yellow poplar can rarely build up a heavy layer of leaf litter, but on the other hand this rapid deterioration of the leaves is largely responsible for one of the best porous, friable topsoils in the southern Appalachians.

Mixed plantations may, however, be deemed in general less risky at the present stage of observation of second-growth stands. If so, the question of a desirable mixture is not difficult to answer. The species which are commonly found with yellow poplar are species which do well in mixed plantations, and the choice will depend upon the purpose of the owner, and upon the soil and climatic qualities of the particular site. In the best southern mountain coves no species except chestnut has shown the ability to compete successfully with yellow poplar in natural seedling stands. On drier poplar sites, northern white pine, shortleaf pine, pitch pine, white oak, and black oak will succeed in maintaining a place in the upper crown cover.

Black locust is very commonly found with yellow poplar in second-growth stands. Because of its early rapid height growth, it competes very favorably up to 20 to 25 years, when the crown of the locust becomes thin and diameter growth falls off abruptly. At this stage in plantations of locust and poplar, the locust may be utilized for posts, poles, or whatever purpose it may serve, and the yellow poplar left to continue its growth. A suitable mixture in such a stand would consist of half to three-fourths locust, with the poplar spaced 14 feet apart.

While black walnut is also commonly found in mixture with yellow poplar in natural stands, these two species will probably not do well in mixed plantations for timber production only. The only purpose in mixing them would be to produce walnut saw timber with a subordinate crop of yellow poplar pulpwood. Both species require full

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light and produce open stands, and the walnut must be given a start in growth for several years or the poplar will dominate it (*3*).

A striking example of an excellent mixed stand encouraged by wise management is found at the Cowan's Gap ranger station on the Buchanan State Forest, near McConnellsburg, Pa. In a Norway spruce and white pine plantation established in 1911–1914, various hardwood species including yellow poplar were seeded into the openings between the planted trees. In 1929 a cleaning of the competing hardwood growth left all good yellow poplar, with the result that there is now an excellent mixture of spruce, pine, and poplar. This mixed stand of conifers and hardwoods will undoubtedly become more valuable than the conifer stand alone, and growing conditions on the site will constantly improve.

If yellow poplar is grown in mixture with northern white pine, the slow early growth rate of the pine will give the poplar the advantage in height growth. On the best yellow poplar sites this advance growth will be too rapid and the pine will become permanently overtopped. The natural stand represented by Table 7 gives some indication of what might be expected from a plantation of this mixture, although this site was better suited to northern white pine than to poplar—a light sandy soil not well supplied with water.

TABLE 7.—*Number of northern white pine and yellow poplar trees per acre in a 19-year-old mixed seedling stand, Unicoi County, Tenn.*

Diameter breast high	White pine			Yellow poplar		
	Dominants	Intermediates	Suppressed trees	Dominants	Intermediates	Suppressed trees
1 inch			40			360
2 inches			910		270	570
3 inches		370	430	240	140	
4 inches	280	180	10	70		
5-7 inches	230			20		
Total	510	550	1,390	330	410	930

On the great majority of old fields, planting yellow poplar in mixture with shortleaf pine or pitch pine is of doubtful expediency. On the best soils the pine will be outshaded, and on the poorer soils the poplar will be overtopped by the pine.

Table 8 records the outcome of a natural mixture of yellow poplar with white ash, sugar maple, and black locust. Although of smaller diameter than the yellow poplar, the locust trees are the tallest in the stand, the larger ones being from 45 to 50 feet high. The poplar is 40 to 45 feet in height, the ash 30 to 45 feet, and the maple 25 to 40 feet. The ash, locust, and yellow poplar form the dominant crown class at the present time. The maple forms the lower story and will probably be joined later by ash. In this stand, the ash and maple show evidence of ability to endure shade and to continue to live as an understory to the stand. In a few years the locust can be removed, leaving a mixture of about one-third poplar and two-thirds ash as the dominant part of the stand.

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TABLE 8.—*Number of yellow poplar and other species per acre in a 22-year-old mixed stand on an old field*

Diameter breast high	Yellow poplar	White ash	Locust	Sugar maple
2 inches	1	120	80	290
3 inches		40	50	40
4–5 inches		80	50	20
6–9 inches	40	60	40	10
Total	41	300	220	360

Spruce does not occur naturally as an understory to yellow poplar, but such mixtures might prove advantageous where most of the poplar is intended to be utilized as an early crop, since it would then be supplanted by the spruce underneath it. In this way successive pulpwood crops of poplar and spruce might be obtained while selected yellow poplars were permitted to grow to full development as a third crop of saw timber.

The fact that yellow poplar may be used for planting in many places, from the level of the coastal plains to an elevation of nearly 4,500 feet in the mountains, opens the way to the possibility of many more mixtures than those discussed. The determination of the proper mixtures is still a matter of experiment.

YIELDS FROM PLANTATIONS

Few yellow poplar plantations are old enough to give much indication of the yields which may be expected from planted stands, although the early growth rate seems to be comparable with that of natural stands on equivalent sites. Many studies are necessary before specific statements of growth rate can be safely made. On several plots measured for yield in a 19-year-old plantation near Pineville, Ky., the yield of trees 5 inches and more d.b.h. in the better parts equaled approximately a cord of felled wood per acre per year, or about 19 cords in 19 years. (Fig. 15.) The yields on all the plots measured were equal to or better than the yields from natural stands on equally good sites. More uniform spacing in plantations may well result in greater early yield in planted than in natural stands.

ROTATION AGE AS A FACTOR IN MANAGEMENT

The time for the final cutting of a stand of yellow poplar will be varied arbitrarily according to the utilization of the material grown or the financial demands made upon the property. Pulpwood may be cut from yellow poplar stands as young as 20 years on good sites, although to do so will be to lose advantage of the rapid growth that takes place on such sites for some time after this period. The greatest mean annual volume growth of pulpwood on average yellow poplar land will be obtained at about 50 years. If it is intended to produce saw timber, this point of maximum growth will probably be advanced to 70 years in stands which have not been thinned. Exact determination of this age must await extension of second-growth yield tables.

Another method of reckoning rotation age may be based upon the accumulation of carrying charges, which will represent the rotation of

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greatest income and will generally be shorter than the rotation of greatest mean annual volume production. The rate of interest required by the owner, the amount of the initial investment, and the annual outlay for taxes and administration, are all factors which

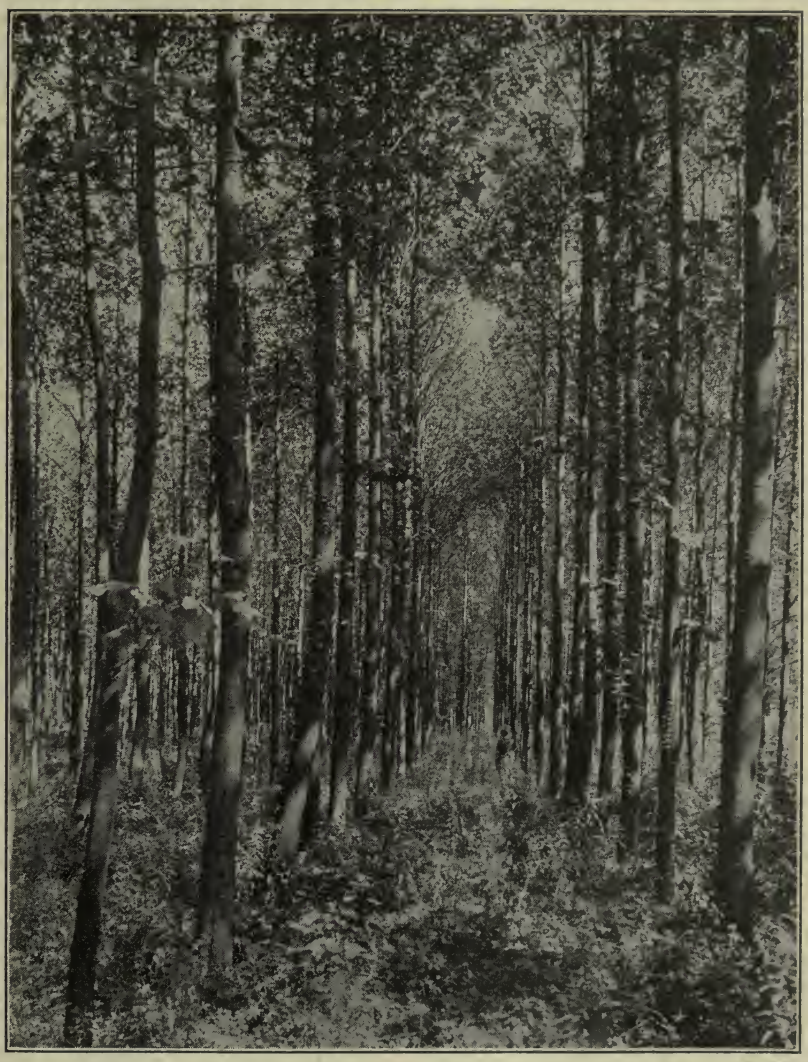

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FIGURE 15.—A 19-year-old yellow poplar plantation near Pineville, Ky., yielding about 1 cord per acre per year

affect the financial return on any acre of forest land and, consequently, the policy of the owner.

With an interest rate of 5 per cent compounded annually, cordwood at $3 per cord, and annual expenses for taxes and administration at 25 cents per acre per year, the highest soil rental is obtained at about 25 years for unthinned stands on average poplar land, or possibly as

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late as 30 years if it is considered that the increased size of the trees will somewhat reduce the cost of cutting per cord and yet increase the quality of the product. Reduction of the interest rate will extend the period further; and the removal of wood by early thinning, to save trees which would otherwise be lost, will increase the period of rotation to an age that will more nearly conform with that of the greatest mean annual growth in cubic feet.

For saw timber, with taxes and administration fixed at 25 cents per acre per year, interest at 5 per cent, and stumpage value at $8 per M feet b. m., the greatest soil rental will be obtained at 35 to 40 years. Rapid increase in quality and revenue obtained from thinnings may easily extend this period to 50 years. The most careful management of poplar stands will be required to extend the financial rotation, based upon the greatest soil rental, to the period of greatest mean annual board-foot increment, or 70 years. However, the earlier the cutting for saw timber the larger the percentage of sapwood in the lumber and the lower the price that it will bring. The increase in stumpage value due to increase in quality offers a considerable inducement to extend the saw-timber rotation to 70 years where possible.

RECOMMENDATIONS

Recommendations for the management of yellow poplar are concerned mainly with second-growth stands, since the area of old-growth forest containing yellow poplar is comparatively small. The retention of seed trees of this species, well placed, will materially increase the seedling regeneration of old-growth cuttings and should be practiced wherever such trees can be salvaged later, or where it does not represent too large an investment in the new crop. The only other feasible practice is heavy cutting of old-growth forest to give whatever yellow poplar seeds may be blown in or may be already present sufficient light and room for germination and vigorous seedling growth. This will result in scattered yellow poplar trees in the new stand.

Second-growth forests containing yellow poplar will prove most profitable if so managed as to increase the proportion of the species on sites with good, moist soil. Yellow poplar trees under 30 years of age in such stands may be expected to reproduce by sprouts with reasonable success, but this will not result in an increased representation of yellow poplar or in improvement in the growing stock.

A high percentage of yellow poplar in the stand can be obtained through natural seeding by several successive steps. Yellow poplar seed trees must be allowed to reach effective seed-bearing age (generally 35 to 40 years) before the stand is cut and enough of these should be retained (probably five per acre in most cuttings) to assure ample reproduction. Cutting must be heavy, permitting good germination and rapid early development of seedlings. If the less valuable species interfere with the growth of yellow poplar seedlings by overtopping and shading them, a release cutting will be necessary, and this should not be delayed until the poplar trees have lost their vigorous growth rate.

The time and character of each of these operations will be determined by the cost and by the willingness of the owner to make an investment in labor with the expectation of a future return.

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Abandoned fields suited to yellow poplar, which for lack of seed trees are not being reseeded naturally, can often be profitably planted to this species, thus preventing occupation of these sites by inferior species and providing sources of yellow poplar seed for subsequent natural regeneration. Sites should be moist and well drained, with good depth of soil. Openings on cut-over forest land where no poplar seed trees are available should also be planted for similar reasons. Severely eroded and other drier areas in old fields, even though originally occupied by the species, should not be planted with poplar but with pines or other species suited to dry sites.

FINANCIAL RETURNS

The computation of financial returns from the production of yellow poplar involves many speculative elements. Profit or loss depends largely upon such conditions as accessibility to market, initial investment, interest rate, taxes, and lumber and pulpwood values. Anything resembling a close estimate is impossible.

STUMPAGE VALUES AND LUMBER AND PULPWOOD PRICES

During a period of approximately 30 years, production of yellow poplar lumber has decreased from what was perhaps its high point, in 1899, of 1,115,000,000 board feet annually to a trifle less than 436,000,000 board feet in 1929. It is evident, however, from Figure 16, which gives the trend of lumber production and lumber prices for this period, that 320,000,000 board feet would fairly represent the average for the past 15 years. To what degree the sharp decline for 1930 represents any permanent trend is of course problematical.

Each year during this period an increasing proportion of second-growth yellow poplar has come on the market, partly because of the dwindling supply of old growth. This means that during this time the percentage of lower grades of lumber, especially of the sap grade, has been increased, but, in spite of this (Table 3, p. 13), the average price of all grades of yellow poplar at the mill has increased from about $14 in 1899 to more than $41.50 in 1929. This figure of approximately $41.50 is virtually a return to the price of 1919 and appears from Figure 16 to represent a fairly average price for the last 10 or 11 years.

No general logging and milling costs can be applied throughout the field of production, since so many variable factors influence these costs. However, using the average 1929 mill-run price (approximately $41.50) as a basis and assuming logging and milling costs of $20 per thousand as well as a profit of 20 per cent on the sale price, the stumpage value per thousand board feet would work out at $13.20, which compares very well with the average stumpage price given in Table 9 for the year 1929. This price of $12.14 in Table 9 is of course weighted by the much lower prices paid for the smaller material cut for pulpwood. It is probable that costs of $20 per thousand represent a reasonable average. Most tracts include a mixture of species, a fact which obscures both the logging costs and stumpage price for yellow poplar. But if yellow poplar were cut alone, the cost of logging would be excessively high, since the trees are usually rather widely scattered.

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TABLE 9.—*Average stumpage and log prices and price range of yellow poplar, all States, 1928–1930*

Product and year	Average price	Price range	Product and year	Average price	Price range
Stumpage:			Logs:		
1928	$6.83	$2.00–$35.00	1928	$27.64	$11.00–$61.50
1929	12.14	2.00– 40.00	1929	35.09	13.75– 80.00
1930	8.79	1.00– 30.00	1930	28.70	6.00–[1] 278.08

[1] Influenced by the inclusion of a quantity of high-grade veneer logs. (Fig. 17.)

Second-growth yellow poplar will produce a high percentage of sap-grade lumber but will be very free from other defects. If well manufactured and protected from sap stain until seasoned, the clear sap lumber will command a price comparable with the mill run of the

FIGURE 16.—Yellow poplar lumber production and average value per 1,000 feet board measure, f. o. b. mill, recorded years, 1899 and 1904–1930

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present forest-grown poplar. New York quotations of wholesale prices for the sap grade of poplar have averaged for the past 25 years about double the average mill-run price for all grades of yellow poplar at the point of production. This should allow ample margin for freight, selling costs, and profit, and still leave a price comparable with the value of mill run for all grades. The logical assumption is that the usually accepted stumpage prices for poplar are much below its actual value and that stumpage values of $10 or $12 could now be justified for large-size second growth of average accessibility and distance from market.

An important consideration in any estimate of the profitable production of yellow poplar lumber is the possibility of loss in logging

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FIGURE 17.—Samples from a curly yellow poplar veneer log; the wedge-shaped piece shows a tangential section; the others, radial sections. Grown in Union County, Ga.

small trees. The cost of logging and milling small logs may even exceed the value of the lumber produced from them. The diameter of a yellow poplar tree which can be logged and sawed at a profit will vary with changes in lumber prices, accessibility, and other factors of logging and milling costs. Ashe (*2*) has given examples illustrating the conditions which determine the size limit down to which yellow poplar and other trees can be cut profitably.

Cutting yellow poplar for pulpwood, which has in a number of cases been disastrous to the further production of yellow poplar on the areas so cut, has perhaps already reached its peak and is on the decline. Such would appear to be the evidence furnished by Figure 18. Although the production curve in Figure 18 is based on consumption figures in Table 4, for a species like yellow poplar that has

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never been forced on the market these values are probably quite accurately representative of the actual cut of pulpwood.

The high prices paid in 1920 and 1921, which doubtless had a great deal to do with the considerable increase in the production of yellow poplar pulpwood from 1921 on, no longer rule, and the indication appears to be that the very considerable falling off in prices since 1927 has had its effect in bringing yellow poplar production back to the intermediate stage of 1922 and 1923. It may be expected that pulpwood prices will rise with the rise in other values, but it is doubtful that production will soon reach the height of 1924 to 1929. As has

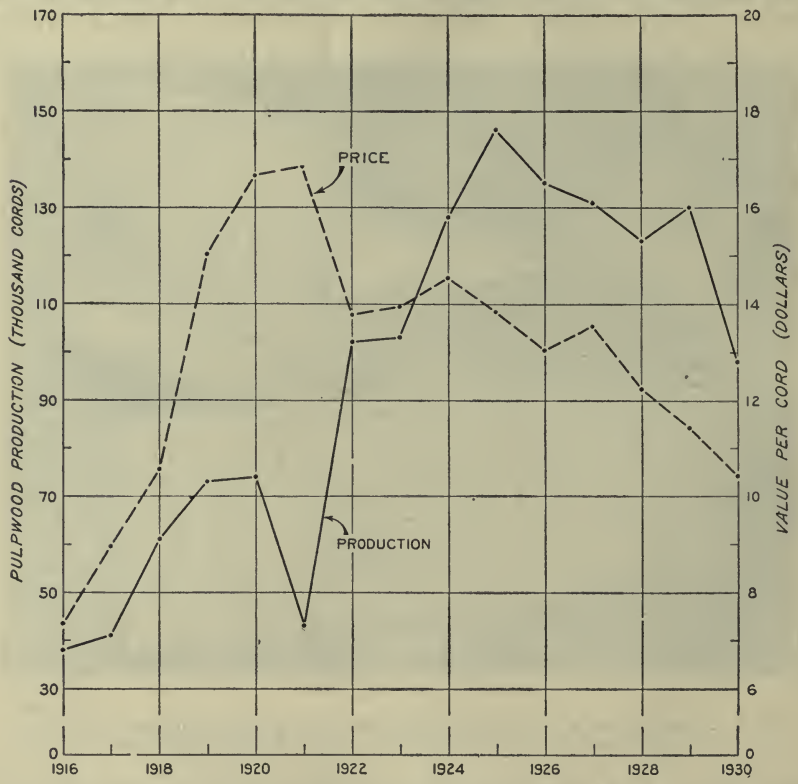

FIGURE 18.—Yellow poplar pulpwood production and average price f. o. b. mill, per cord, 1916–1930

been already intimated, it is to be hoped that the young stands of yellow poplar remaining and those that will later come to pulpwood size may be spared to realize the vigorous growth of which they are capable. The price of $10.40 a cord for poplar pulpwood corresponds to a lumber value of hardly more than $21 per thousand board feet, which, considering that logging costs are probably as high for pulpwood as for lumber logs, if not higher, constitutes a very much lower return per acre for pulpwood than for saw timber.

The method of computing actual returns from saw-log production of yellow poplar may be illustrated by the following example.

In this instance, the cost of production has been considered as the cost of the land with the annual charge for administration and taxes,

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all computed with compound interest at 4 per cent to the end of the rotation. Natural reproduction is assumed, and no cost for planting is considered. If such a cost were involved, it would be treated as an initial investment and be carried with interest to the end of the rotation. A charge of 10 cents per acre per year is fixed for administration and protection without taking into account variations in quality of the land. Annual taxes are fixed at 1 per cent of the full value of the land, this amount to be paid on land alone. In addition, 10 per cent of the gross revenue is deducted as a yield or severance tax on the timber at the end of the rotation.

Stumpage is fixed at $8 per thousand board feet as a reasonable price for all grades without regard for the obvious fact that the larger timber at 50 years will cut a much higher grade of lumber than can be cut from the smaller trees. The land is valued at $12 per acre with interest for the full period but with the value of the land deducted at the end of the rotation. This is computed for 50 years as follows:

$$\$12\ (1.04^{50}-1)=\$73.28$$

Taxes and administration at 22 cents per acre per year amount to—

$$\$0.22\ \frac{(1.04^{50}-1)}{.04}=\$33.59$$

The yield of 40,200 board feet per acre (International rule) for site index 110 (Table 17), valued at $7.20 per thousand board feet after deduction of 10 per cent yield tax, gives a net yield of $289.44 or, after deducting the cost of production, a net profit of $182.57 per acre.

Table 10 shows the profit which may be expected on good, medium, and poor sites with land alone valued at $12, $8, and $4, according to its productivity, compared as in the preceding example.

TABLE 10.—*Net profit or loss per acre to be expected from crops of yellow poplar on three qualities of site at different ages*

Age	Good site [1]	Medium site [2]	Poor site [3]	Age	Good site [1]	Medium site [2]	Poor site [3]
10	−$6.96			35	$101.44	$52.81	$10.31
15	−2.50	−$5.33	−$3.13	40	130.40	69.85	20.32
20	16.46	−.49	−4.25	45	158.28	85.65	28.49
25	44.29	15.89	−2.41	50	182.57	99.35	36.28
30	73.06	34.67	2.26				

[1] Site index 110, valued at $12 an acre.
[2] Site index 90, valued at $8 an acre.
[3] Site index 70, valued at $4 an acre.

The negative values given for young stands indicate a loss at these ages. Assuming land values of $6, $4, and $2 per acre for good, medium, and poor qualities of land, with other conditions as stated in the example given, net profits of $228.37, $129.88, and $51.55, respectively, can be obtained in 50 years. Assuming land values of $18, $12, and $6 per acre, net profits of $136.77, $68.81, and $21.01 can be obtained in the same period. These estimates illustrate the effect of varying the initial investment.

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The influence of high interest rate is shown by contrasting the effect of 4 per cent and 5 per cent compound interest on these profits. With interest computed at 4 per cent, compounded annually, the profit per acre on a good site has been shown to be $182.57; with the interest rate at 5 per cent compounded annually, this profit is reduced to $117.77.

SUMMARY

Yellow poplar has many good characteristics—the fine quality of its wood, good form, rapid growth, freedom from serious injury by disease and insects, and wide though scattered distribution—which combine to make it one of the most valuable of hardwood trees. Since this species is especially well adapted to the better forest soils in the region of its growth, it should be encouraged on such sites.

Natural regeneration by seed and sprouts will constitute the chief sources of new growth on areas now occupied by yellow poplar. Success in obtaining natural regeneration of yellow poplar can be better assured by giving attention to the following considerations based on natural characteristics of the species:

Seed trees must be of seed-bearing age and so located as to be effective.

Good seed crops may be expected annually and extra heavy crops at irregular intervals.

Seed will average 12 to 15 per cent viability.

Seed will blow to a distance of four to five times the height at the source.

Seed will germinate only if it has an ample and constant moisture supply and is free from the heavy cover of litter normally found in hardwood forests.

Early germination and vigorous growth in the first season are needed to assure a good percentage of survival of seedlings. Excessive competition of other vegetation or dryness of the site will prevent such growth.

Frost heaving, smothering by leaf litter, and shading are important causes of loss of natural seedlings in ungrazed areas; this loss is very heavy among underdeveloped seedlings less than a year old.

Yellow poplar seedlings that have competed successfully for leadership over other growth of equal age will, after the first four or five years, have entered upon a vigorous height growth which will enable them to retain their place in the upper crown level.

Yellow poplar will sprout vigorously only from young and vigorous root systems but sprout growth once started will maintain or recover leadership over all other tree and shrub growth of the same age.

The best natural seedling regeneration has occurred in abandoned fields where the competition of hardwood sprouts was negligible, the climate and soil-moisture conditions were favorable, and seed trees of yellow poplar were standing adjacent.

Plantations of yellow poplar on well-chosen sites have made a growth equal to that of stands seeded naturally on similar areas. Also, planting stock can be produced at a low cost, wide spacing in field planting is possible, and establishment is therefore cheap. Difficulties in the production of planting stock and failures in field planting largely disappear with a better understanding of the limitations of the species.

Clear cutting of old-growth stands containing some yellow poplar has resulted in certain instances in good second growth of this species. The lack of sprouting capacity of stumps of old trees and the suppressed condition of advance growth of other species in the old stand made this possible.

The heavy cutting practiced during the last two decades in the extensive ungrazed forests of the Appalachian Mountains and Plateau

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has resulted in increased establishment of yellow poplar segs.edlin The survival of these seedlings depends chiefly on the age and sprouting vigor of the stand when cut. In more vigorous young stands many of the yellow poplar seedlings will be overtopped and distorted by sprouts of less valuable trees, and on good sites the release of the poplar by cutting or other measures is desirable.

Vigorous, well-stocked stands of other young hardwoods can not be economically replaced with yellow poplar, but stands which contain this species should be managed to promote its growth and later regeneration.

Clear cutting of young yellow poplar for pulpwood threatens the future production of this species through elimination of seed trees. This practice results in small profit to the owner and should be abandoned in favor of a practice which will produce some trees of sawtimber size that will be effective for seeding.

Success in the production of yellow poplar on land suited to its growth requires protection from fire and grazing. One fire may destroy all chance of profit from the fire-damaged stand; protection from grazing stock is imperative during the reproduction stage.

Methods of management of stands containing yellow poplar will vary because of differences in composition, accessibility, invested value, and requirements of the owner. Any of these factors may affect the length of periods between cuttings and the amount of care which can be given the stand throughout its life. The best results will be obtained where close supervision and intensive improvement of stands are possible.

LITERATURE CITED

(1) Anonymous.
1926. THE COMMERCIAL WOODS OF THE SOUTH. South. Lumberman 125 (1629) : 163–179, illus.

(2) Ashe, W. W.
1926. RELATION OF SIZE OF TREES TO LOGGING COSTS, STUMPAGE VALUES, AND PROFITS. South. Lumberman 125 (1620) : 31–32.

(3) Baker, F. S.
1921. BLACK WALNUT: ITS GROWTH AND MANAGEMENT. U. S. Dept. Agr. Bul. 933, 43 p., illus.

(4) ———
1925. THE CONSTRUCTION OF TAPER CURVES. Jour. Agr. Research 30: 609–624, illus.

(5) Frothingham, E. H.
1921. CLASSIFYING FOREST SITES BY HEIGHT GROWTH. Jour. Forestry 19 : 374–381.

(6) Helphenstine, R. K., Jr.
1923. WOOD-USING INDUSTRIES OF NORTH CAROLINA. N. C. Dept. Conserv. and Devlpmt. Bul. 30, 105 p., illus.

(7) Henry, A. J.
1906. CLIMATOLOGY OF THE UNITED STATES. U. S. Dept. Agr., Weather Bur. Bul. Q, 1012 p., illus.

(8) Hopkins, A. D.
1904. INSECT INJURIES TO HARDWOOD FOREST TREES. U. S. Dept. Agr. Yearbook 1903 : 313–328, illus.

(9) Korstian, C. F., and Mackinney, A. L.
1931. PLANTING VERSUS DIRECT SEEDING OF YELLOW POPLAR IN THE SOUTHERN APPALACHIAN REGION. Jour. Forestry 29 : 1178–1181.

(10) McArdle, R. E.
1930. THE YIELD OF DOUGLAS FIR IN THE PACIFIC NORTHWEST. U. S. Dept. Agr. Tech. Bul. 201, 64 p., illus.

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(11) SIMS, I. H.
1932. ESTABLISHMENT AND SURVIVAL OF YELLOW POPLAR FOLLOWING A CLEAR CUTTING IN THE SOUTHERN APPALACHIANS. Jour. Forestry 30 : 409–414, illus.

(12) TOUMEY, J. W., and KORSTIAN, C. F.
1931. SEEDING AND PLANTING IN THE PRACTICE OF FORESTRY: A MANUAL FOR THE GUIDANCE OF FORESTY STUDENTS, FORESTERS, NURSERYMEN, FOREST OWNERS, AND FARMERS. Ed. 2, rev. and enl., 507 p., illus. New York.

(13) UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE.
1920. TIMBER DEPLETION, LUMBER PRICES, LUMBER EXPORTS, AND CONCENTRATION OF TIMBER OWNERSHIP. Rpt. on Senate Resolution 311, ed. 3, 73 p., illus.

(14) ———
1927. AMERICAN FORESTS AND FOREST PRODUCTS. U. S. Dept. Agr. Statis. Bul. 21, 324 p., illus.

(15) ———
1929. VOLUME, YIELD, AND STAND TABLES FOR SECOND-GROWTH SOUTHERN PINES. U. S. Dept. Agr. Misc. Pub. 50, 202 p., illus.

(16) ——— WEATHER BUREAU.
1912. SUMMARIES OF CLIMATOLOGICAL DATA BY SECTIONS. U. S. Dept. Agr., Weather Bur. Bul. W, 2 v., illus.

APPENDIX

VOLUME AND YIELD TABLES

TABLE 11.—*Yellow poplar volume table*[1] *for trees over 100 years old (Scribner Decimal C rule), southern Appalachians*

Diameter breast high (inches)	Volume in board feet, in tens, when height of tree is—								Diameter inside of bark of top	Basis
	70 feet	80 feet	90 feet	100 feet	110 feet	120 feet	130 feet	140 feet		
									Inches	*Trees*
10	6	7							6	1
11	7	9							7	1
12	9	11	14						7	4
13	11	14	17						8	3
14	13	17	20	22					8	3
15	16	20	23	26					8	4
16	19	23	27	30	31				8	8
17	22	27	31	34	37				9	16
18	25	31	36	39	43	47			9	16
19	29	35	41	45	50	54			9	18
20	33	39	46	52	58	63	68		10	20
21		44	52	59	66	72	77		10	20
22		49	58	67	74	81	86	91	10	27
23		54	64	75	83	91	96	101	11	27
24		60	71	84	91	101	106	112	11	22
25		66	78	93	102	111	117	123	12	32
26		73	86	102	112	122	129	136	12	29
27		80	94	111	123	133	141	148	12	21
28		87	103	121	134	145	154	162	13	21
29		95	113	132	145	158	168	176	13	19
30		104	124	144	158	171	181	190	14	22
31		113	135	155	171	185	195	205	14	14
32		123	146	168	184	199	210	220	14	13
33		133	158	181	198	214	225	235	15	14
34			171	194	213	228	239	250	15	10
35			183	207	226	243	254	265	16	5
36			196	220	240	257	269	281	16	3
37			209	233	254	272	285	297	16	
38			222	246	268	286	301	314	17	5
39			235	260	281	300	317	331	17	7
40			248	273	295	314	334	348	17	2
Total										407

[1] This table was made from taper curves by scaling the merchantable length in log lengths to the top diameters shown. Logs were 16.3 feet long whenever possible, with some 14.3 feet, 12.3 feet, and 10.3 feet logs to avoid waste. The assumed stump height was 2 feet. Top diameter inside bark. U. S. Forest-Service Region 7, 1915.

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TABLE 12.—*Yellow poplar volume table*[1] *for trees more than 100 years old (Scribner Decimal C rule), southern Appalachians*

Diameter breast high (inches)	Volume in board feet, in tens, when the number of 16-foot logs in tree is—						Diameter inside of bark of top	Basis
	1	2	3	4	5	6		
							Inches	*Trees*
10	2	5	8				6	1
11	3	6	10				7	1
12	3	7	12	18			7	4
13	3	8	15	21			8	3
14	3	9	17	24			8	3
15	3	10	19	27			8	4
16	3	12	22	31			8	8
17	4	13	24	35	42		9	16
18	4	15	27	39	47		9	16
19	5	16	30	44	54		9	18
20	5	18	33	48	61	75	10	20
21		20	36	54	69	84	10	20
22		22	39	59	76	93	10	27
23		25	42	65	85	103	11	27
24		27	46	72	94	113	11	22
25		30	50	79	103	123	12	32
26		32	54	86	112	135	12	29
27		35	58	94	122	147	12	21
28		38	63	102	133	159	13	21
29		40	68	110	144	172	13	19
30		43	74	118	156	185	14	22
31			79	127	168	199	14	14
32			85	136	181	214	14	13
33			91	146	193	228	15	14
34			98	156	206	244	15	10
35			104	167	219	259	16	5
36			112	178	232	275	16	3
37			119	191	245	291	16	
38			126	204	258	307	17	5
39			133	216	271	322	17	7
40			140	230	284	338	17	2
Total								407

[1] This table is based on taper curves. Height of stump, 2 feet. Top diameters measured inside bark.

TABLE 13.—*Volume table*[1] *in cubic feet (total volume) for second-growth yellow poplar, Pike County, Ohio, and Fairfax County, Va.*

Diameter breast high outside bark (inches)	Volume in cubic feet when height of tree is—						Basis
	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
							Trees
5	2.2	2.8					8
6	3.5	4.2					10
7	4.9	5.8	6.8				50
8	6.3	7.5	8.8	10.1			62
9	8.0	9.5	11.2	12.8			66
10	9.7	11.8	13.7	15.8	17.8		55
11	11.5	14.2	16.7	19.2	21.7		75
12	13.5	16.6	19.7	22.8	25.9	29.0	49
13		19.4	22.9	26.6	30.2	33.8	51
14		22.2	26.4	30.7	34.9	39.2	27
15		25.0	29.9	34.8	39.7	44.7	16
16			33.9	39.4	45.0	50.5	20
17			37.8	44.1	50.4	56.7	12
18			41.8	49.0	56.1	63.3	5
19				54.3	62.0	69.8	5
20				59.6	68.0	76.4	
21					74.5	83.9	
22					81.3	91.2	1
Total							512

[1] From taper tables computed by the form quotient method. Volume includes total stem without bark.

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TABLE 14.—*Cubic-foot volume table*[1] *(merchantable volume) for second-growth yellow poplar Pike County, Ohio, and Fairfax County, Va.*

Diameter breast high outside bark (inches)	Volume in cubic feet when height of tree is—						Basis
	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
							Trees
5	1.8	2.2					8
6	3.0	3.7					10
7	4.2	5.2	6.2				50
8	5.6	6.9	8.1	9.4			62
9	7.2	8.8	10.5	12.0			66
10	8.9	10.9	13.0	15.0	17.0		55
11	10.6	13.1	15.6	18.1	20.6		75
12	12.4	15.5	18.5	21.6	24.7	27.7	49
13		18.0	21.6	25.2	28.8	32.5	51
14		20.7	24.9	29.1	33.3	37.5	27
15		23.6	28.4	33.2	38.0	42.8	16
16			31.8	37.4	42.9	48.5	20
17			35.5	41.8	48.1	54.5	12
18			39.5	46.5	53.6	60.7	5
19				51.5	59.2	66.9	5
20				56.7	65.0	73.5	
21					71.6	80.2	
22					78.1	87.7	1
Total							512

[1] From taper tables computed by form quotient method. Stump height, 1 foot; diameter inside bark of top, 3 inches. Volume includes bark.

TABLE 15.—*Board-foot volume table*[1] *for second-growth yellow poplar (Scribner rule), Pike County, Ohio, and Fairfax County, Va.*

Diameter breast high outside bark (inches)	Volume in board feet when height of tree is—						Basis
	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
							Trees
8	15	20	27				62
9	22	30	38	45			66
10	30	40	51	61	71		55
11	37	51	65	78	91		75
12	46	62	80	96	112	129	49
13	56	74	95	115	135	155	51
14		86	112	136	160	184	27
15		100	129	157	187	217	16
16			147	180	216	251	20
17			165	205	246	287	12
18			184	231	278	325	5
19				259	312	367	5
20				289	348	409	
21					386	453	
22					427	501	1
Total							444

[1] Volume scaled by Scribner rule from taper diagrams. Stump 1 foot high and top 6 inches in diameter inside bark.

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TABLE 16.—*Board-foot volume table* [1] *for second-growth yellow poplar (International rule), Pike County, Ohio, and Fairfax County, Va.*

Diameter breast high outside bark (inches)	Volume in board feet when height of tree is—						Basis
	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
							Trees
8	16	21	26				62
9	26	34	43	53			66
10	36	48	62	75	88		55
11	46	64	81	99	117		75
12	56	79	102	124	146	168	49
13		96	123	149	176	203	51
14		113	145	177	209	241	27
15		129	167	205	242	280	16
16			189	233	278	323	20
17			212	264	315	367	12
18			236	294	354	412	5
19				327	394	462	5
20				363	437	510	
21					481	563	
22					529	617	1
Total							444

[1] Volume scaled by International rule (1/8-inch kerf) from taper diagrams. Stump 1 foot high and top 6 inches in diameter inside bark.

TABLE 17.—*Normal yield table for second-growth yellow poplar*

DOMINANT STAND

Age (years)	Total height in feet on site index [1]—						
	60	70	80	90	100	110	120
10		28	32	36	40	44	48
15		39	45	51	57	62	68
20		47	54	61	68	75	81
25		53	61	69	76	84	91
30		58	66	75	83	91	99
35		62	71	80	88	97	106
40		65	74	84	93	102	111
45		68	77	87	97	106	116
50		70	80	90	100	110	120

TOTAL STAND 5 INCHES D. B. H. AND MORE

Age (years)	Number of trees per acre						
10			18	66	92	116	135
15	58	130	173	200	228	238	246
20	150	206	235	252	264	266	264
25	206	246	264	268	269	264	256
30	218	264	268	260	252	244	234
35	258	268	260	246	236	224	212
40	265	264	246	230	218	204	190
45	266	253	230	212	198	184	168
50	264	240	214	194	176	164	148
Age (years)	**Diameter breast high in inches**						
10					5.1	5.2	5.3
15		5.3	5.5	5.8	6.0	6.2	6.4
20	5.4	5.9	6.3	6.6	6.9	7.2	7.5
25	5.9	6.4	6.9	7.4	7.8	8.2	8.6
30	6.3	7.0	7.6	8.3	8.8	9.3	9.8
35	6.7	7.6	8.4	9.2	9.9	10.5	11.1
40	7.2	8.2	9.3	10.1	10.9	11.6	12.4
45	7.7	8.9	10.1	11.1	12.0	12.9	13.6
50	8.2	9.7	11.0	12.2	13.2	14.1	14.9

[1] The 50-year values are site indices.

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TABLE 17.—*Normal yield table for second-growth yellow poplar*—Continued

TOTAL STAND 5 INCHES D. B. H. AND MORE—Continued.

Age (years)	Basal area in square feet per acre [2]						
	60	70	80	90	100	110	120
10	-------	-------	2	8	13	17	21
15	8	20	30	38	45	50	55
20	24	39	50	60	68	75	81
25	38	56	69	80	89	97	103
30	51	70	85	97	107	116	123
35	64	84	100	113	125	134	142
40	75	97	114	128	140	150	159
45	86	109	128	143	156	167	176
50	97	122	141	157	172	183	193

Age (years)	Merchantable peeled volume in cubic feet per acre [3]						
10	-------	-------	-------	50	135	250	360
15	80	250	415	600	800	1,000	1,180
20	320	600	880	1,180	1,475	1,765	2,040
25	570	955	1,340	1,745	2,145	2,550	2,900
30	825	1,305	1,800	2,300	2,800	3,320	3,770
35	1,080	1,660	2,250	2,845	3,450	4,070	4,600
40	1,335	2,010	2,690	3,390	4,085	4,800	5,410
45	1,590	2,360	3,130	3,935	4,710	5,510	6,200
50	1,840	2,705	3,570	4,480	5,330	6,220	6,970

TOTAL STAND 8 INCHES D. B. H. AND MORE

Age (years)	Yield in board feet per acre, Scribner rule [4]						
10	-------	-------	-------	50	150	220	360
15	50	100	210	460	870	1,390	1,960
20	190	480	1,030	1,850	2,920	4,220	5,800
25	450	1,180	2,370	4,120	6,180	8,450	10,810
30	930	2,300	4,430	7,110	9,900	12,820	15,810
35	1,540	3,790	6,800	10,200	13,700	17,310	21,050
40	2,370	5,560	9,270	13,300	17,500	21,890	26,500
45	3,380	7,410	11,850	16,600	21,400	26,460	31,560
50	4,580	9,270	14,410	19,800	25,300	30,900	36,600

Age (years)	Yield in board feet per acre, International rule (1/8-inch kerf) [4]						
10	-------	-------	-------	-------	-------	200	400
15	200	400	530	650	1,050	1,600	2,400
20	350	650	1,200	2,000	3,400	5,180	7,000
25	600	1,400	2,790	5,100	7,600	10,200	13,100
30	1,000	2,650	5,500	8,710	12,150	15,600	19,250
35	1,700	4,500	8,300	12,450	16,800	21,250	25,900
40	2,650	6,780	11,230	16,300	21,790	27,350	33,150
45	4,000	9,000	14,380	20,300	26,880	33,750	40,700
50	5,600	11,400	17,620	24,400	32,150	40,200	48,450

[2] Basal area is the cross-sectional area inside bark measured at breast height.
[3] Peeled volume of the merchantable stem, excluding 1-foot stump and top less than 3 inches inside bark. All trees 5 inches and over in diameter outside bark breast high are included.
[4] Stump height, 1 foot; top diameter inside bark, 6 inches.

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BOTANICAL NAMES OF TREES MENTIONED

Common name	Botanical name
Ash, white	*Fraxinus americana* Linn.
Basswood	*Tilia glabra* Vent.
Beech	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* Linn.
Birch, yellow	*Betula lutea* Michx.
Buckeye (sp.)	*Aesculus* spp., Linn.
Butternut	*Juglans cinerea* Linn.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pennsylvanica* Linn. f.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Dogwood	*Cornus florida* Linn.
Elm, American	*Ulmus americana* Linn.
Elm, slippery	*Ulmus fulva*, Michx.
Gum, black	*Nyssa sylvatica* Marsh.
Gum, red	*Liquidambar styraciflua* Linn.
Hemlock, eastern	*Tsuga canadensis* (Linn.) Carr.
Hickory (sp.)	*Hicoria* spp., Raf.
Hophornbeam	*Ostrya virginiana* (Mill.) Koch.
Locust, black	*Robinia pseudoacacia* Linn.
Magnolia, cucumber	*Magnolia acuminata* Linn.
Magnolia, mountain	*Magnolia pyramidata* Pursh.
Maple, red	*Acer rubrum* Linn.
Maple, sugar	*Acer saccharum* Marsh.
Oak, black	*Quercus velutina* Lam.
Oak, chestnut	*Quercus montana* Willd.
Oak, post	*Quercus stellata* Wang.
Oak, red	*Quercus borealis maxima* (Marsh.) Ashe.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, white	*Quercus alba* Linn.
Persimmon	*Diospyros virginiana* Linn.
Pine, northern white	*Pinus strobus* Linn.
Pine, pitch	*Pinus rigida* Mill.
Pine, shortleaf	*Pinus echinata* Mill.
Pine, Virginia	*Pinus virginiana* Mill.
Redbud	*Cercis canadensis* Linn.
Sassafras	*Sassafras variifolium* (Salisb.) Ktze.
Silverbell	*Halesia carolina* Linn.
Sourwood	*Oxydendrum arboreum* (Linn.) DC.
Sumach, staghorn	*Rhus hirta* (Linn.) Sudw.
Walnut, black	*Juglans nigra* Linn.

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Technical Bulletin No. 357 May, 1933

STATE LAND-SETTLEMENT PROBLEMS AND POLICIES IN THE UNITED STATES

BY

W. A. HARTMAN

Senior Agricultural Economist, Division of Land Economics
Bureau of Agricultural Economics

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 357 MAY, 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

STATE LAND-SETTLEMENT PROBLEMS AND POLICIES IN THE UNITED STATES

By W. A. HARTMAN, *Senior Agricultural Economist, Division of Land Economics, Bureau of Agricultural Economics*[1]

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INTRODUCTION

Outgrown and inadequate public, semipublic, and private land-settlement policies are to a certain degree responsible for some of the recent difficulties experienced by American agriculture. Rapid decline in the Nation's population growth and in exports of farm products, substitution of gasoline for horse and mule feed, and improvements in animal husbandry resulted in an economy of at least 50,000,000 acres of crop land since the World War. Expansion of crop land onto former grazing areas and some clearing of forest and cut-over land are in progress, but the total increase is small in comparison with the western expansion of agriculture in the past. The country has been settled but many regional and local readjustments, required by changes in the economic situation as well as by soil depletion and advances in agricultural technic, remain to be made.

[1] The late B. Henderson, of the U. S. Department of Agriculture, in 1923 made a survey of State policies with respect to land settlement. Unpublished notes concerning that survey were drawn upon in planning and conducting the study on which this bulletin is based.

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The agricultural-land policy of the Federal Government has consisted, and it still consists, chiefly in making land easily available to the farmer, leaving him free to make his selection, finance the undertaking, and adjust himself to local conditions. Likewise, with few exceptions, the various States follow the policy of leaving the settler to the mercy of private land-selling agencies and/or of seconding the efforts of those agencies to attract him to the States. To-day, with a limited economic need for expanding the net agricultural area, any land-settlement policy for undeveloped areas based on the unqualified expansion philosophy of the past is a handicap to the development of prosperous farming communities.

Financially embarrassed and defunct drainage, levee, irrigation, and other improvement districts, abandoned farms, and the reversion of large areas of land to public ownership because of tax delinquency are concrete evidences of maladjustments in the use of land in many parts of the country. Disorganized and declining agricultural communities, common in many parts of the country, are natural consequences. Farming in many of these communities and in certain entire areas is doomed to failure. In other areas success is possible only when large-scale farming or some special type of farming is undertaken, alone or in combination with some other major use of land, such as for forestry, recreation of some kind, grazing, or conservation of wild life and fur animals.

Attempts to develop farming communities on lands physically and/or economically unsuited for agriculture result in loss to the county and State as well as to the settler. Settlers will not long continue a struggle to develop a farm on unsuitable land. Those who contract debts they are unable to pay may be forced to leave their farms; others leave voluntarily. Local bankers and business men lose heavily in such adventures and the entire locality, even the State to some extent, is given a bad reputation.

Many public officials, business men, and landowners realize this danger and are interested in curtailing or preventing the great waste of economic and human resources that results from haphazard land-settlement policies. They see that millions of acres now available for farming will not be in real demand for agricultural purposes for many years, and that it would be sound business policy to utilize such lands for other than agricultural purposes.

Consequently, there is great need for the determination of the economic potentialities of land for farming purposes as compared with grazing, forestry, recreation, and other uses; and for the formulation and application of rural-planning programs based on the facts assembled. The adoption of such a program by the Federal Government, and the various States and counties, should result in material benefits, to established farmers, to prospective settlers, and to land-colonization and other land-settlement agencies. As an aid in the formulation of rural-planning programs by States and county officials, public-spirited citizens and others interested in solving the problems of land settlement, the problems encountered and the resulting programs adopted by public agencies in the past have been studied. This bulletin affords a review of such Federal and State policies with reference to land settlement.

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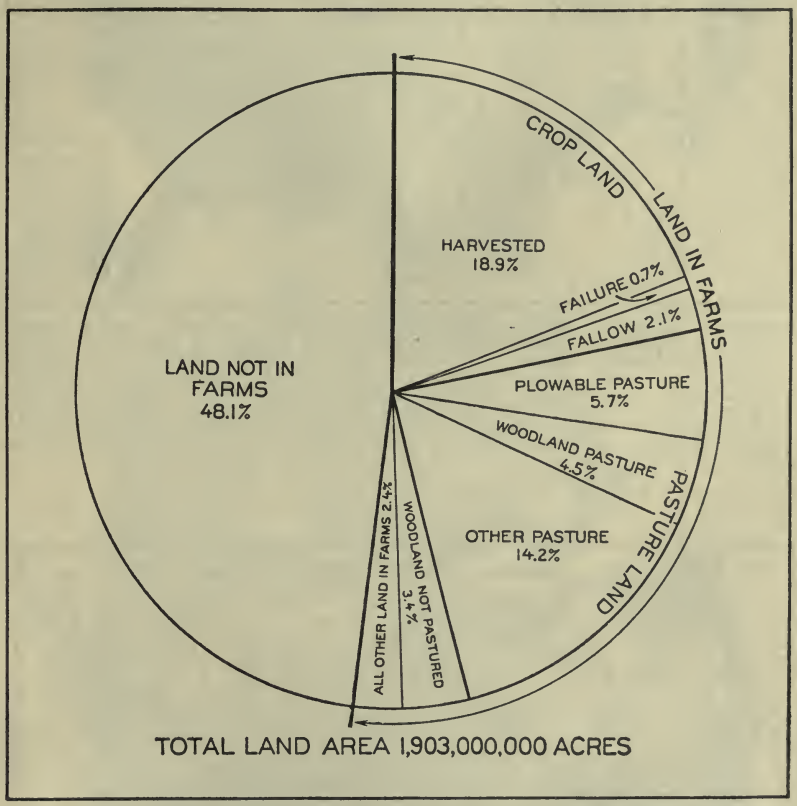
UNDEVELOPED LAND IN THE UNITED STATES

About half (51.9 per cent) of the total land area of the United States (1,903,216,640 acres) was in farms in 1929. Of this total area, slightly less than one-fifth (18.9 per cent) or 359,242,091 acres was in harvested crops in 1929. The idle and fallow plowland totaled 41,287,216 acres, and land on which crops failed totaled 12,706,583 acres (*38*, *Census 1930* [2]). These three classes of crop land



DISTRIBUTION OF LAND IN FARMS BY USE IN 1929 COMPARED WITH OUR TOTAL LAND AREA

FIGURE 1.—Although slightly more than half (51.9 per cent) of the total land area of the continental United States is in farms, less than three-eighths (36.4 per cent) of the land in farms is in harvested crops. This leaves a wide margin from which to draw additional crop acreage when there is an economic need for such expansion

represent less than half (41.9 per cent) of the land area in farms (986,771,016 acres). Figure 1 shows the percentage distribution of all farm land according to use, and shows the percentage relation of land in farms and land not in farms.

There is extreme diversity in precipitation, length of growing season, soil types, and topography even within comparatively small areas. (Figs. 2–5.) It is of paramount importance that the influence of such physical characteristics upon the possible successful

[2] Italic numbers in parentheses refer to Literature, Cited, p. 84.

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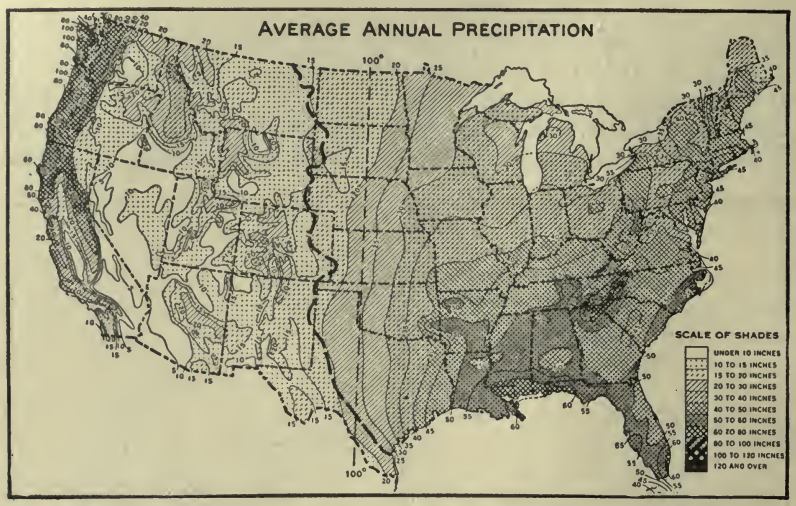

FIGURE 2.—The map emphasizes the fact that for the consideration of land colonization and settlement, the United States should be divided agriculturally into eastern and western parts. The eastern boundary of the grazing and irrigated crops region shown by a broken line is not drawn through points of equal precipitation, but advances diagonally across two of the precipitation zones from 14 inches in the northeastern corner of Montana to 24 inches in southern Texas, where the evaporation is much greater and the rainfall more torrential, and where more moisture is required for crop production. (U. S. Dept. Agr. Misc. Pub. 105 (*3*))

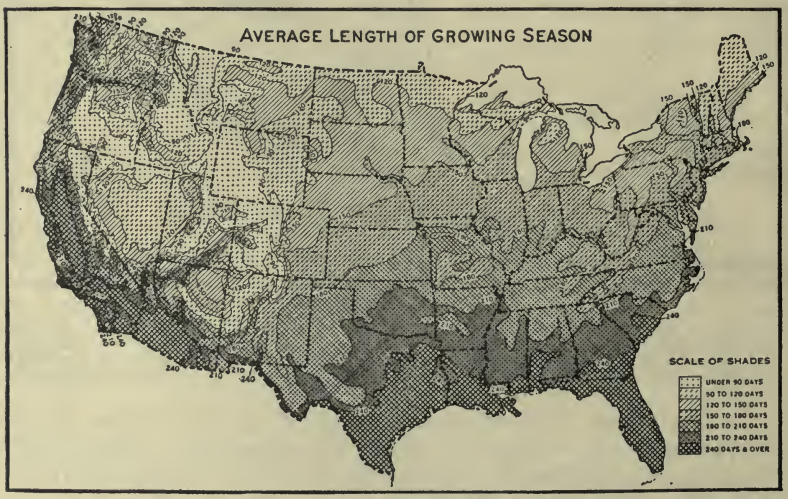

FIGURE 3.—The higher altitude of much of the grazing and irrigated crops region and the drier air, which permits rapid loss of heat at night, are two important causes of the short frost-free season. Over much of this region the frost-free season is shorter than in northern Maine or Minnesota. The powerful influence of the Pacific Ocean and the lesser influence of the Atlantic Ocean in lengthening the growing season along their shores should also be noted. (U. S. Dept. Agr. Misc. Pub. (*3*))

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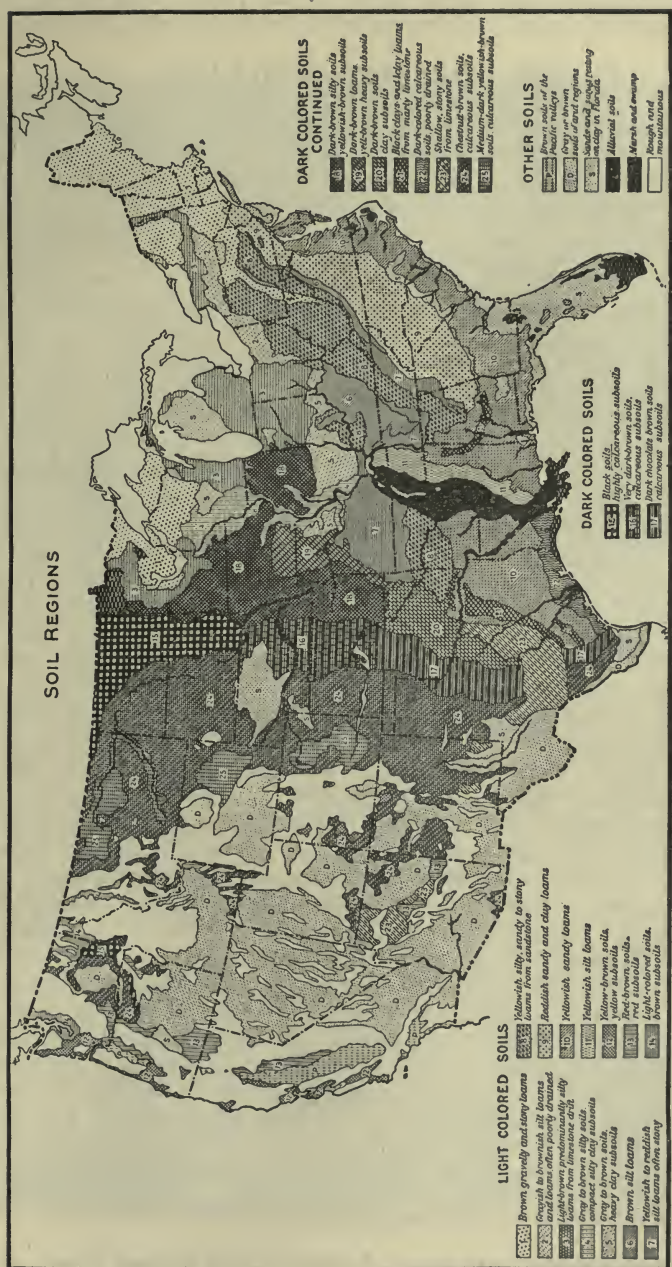

FIGURE 4.—Soils originally or at present covered with forest are normally light colored and are likely to be less fertile than soils in areas of lower rainfall. Grassland soils, in general, are dark colored, the humid prairie soils being commonly almost black and highly fertile, the subhumid prairie soils blackest of all, and the semiarid short-grass plains soils are dark brown or chocolate colored, the color gradually fading to medium brown in areas of lesser rainfall, and to light brown or even ashy gray in desert areas. The light-colored forest soils in the United States totaled about 800,000,000 acres, the dark-colored grassland soils about 600,000,000 acres, and the light-colored arid soils about 500,000,000 acres. (Map prepared by C. F. Marbut and associates, Bureau of Chemistry and Soils, and published in A Graphic Summary of American Agriculture. U. S. Dept. Agr. Misc. Pub. 105 (3, p. 1))

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agricultural development of any particular area be carefully considered in formulating legislation to regulate or to promote land settlement. This has not been done in the past. The consequent wastage of economic and human resources has been very considerable.

CLASSES OF UNDEVELOPED LAND

In order to distinguish between the general type of improvement necessary to bring land under cultivation, undeveloped land is divided into four more or less overlapping classes: Forest and cut-over, drainable, irrigable, and dry-farming and grazing lands.

Forest and Cut-over Land

In 1923 it was estimated that there were approximately 170,000,000 acres (*15, p. 427*) of forest and cut-over land physically capable of being used for crop production after clearing and draining where necessary. Changes that have taken place in this acreage since 1923 have not been estimated, but they are not great. The approximate location of such forest and cut-over land is shown in Figure 6.

Although there are scattered areas of forest or cut-over lands in many parts of the United States, such lands are concentrated in three general regions. One lies in the northern parts of Michigan, Wisconsin, and Minnesota, and is known as the upper Great Lakes region; another extends south and west from Virginia into eastern Texas and Oklahoma, and is known as the southern region; the third, known as the Pacific Northwest, lies in the Sierra section and in northwestern California, in western Oregon, in western and northern Washington, in northern Idaho, and in western Montana.

The labor and expense of clearing cut-over land are important considerations. It is easier and much cheaper to let land grow up to trees again than to remove the brush, down logs, stumps, and stones in preparation for crop production. Actual costs of clearing an acre of land vary greatly. In the Great Lakes States that cost may be as low as $25 and as high as $300 per acre. In the Pacific Northwest the expense of clearing an acre is uniformly higher, primarily because of the predominance of stumps from large slow-rotting coniferous trees. In the southern region the range of costs is generally considered to be about the same as in the upper Great Lakes region.

Large areas of cut-over land, particularly in the coastal plain portion of the southern region, must be drained artificially as well as cleared before crops can be produced. To determine whether it is economically sound to bring such land under cultivation calls for a careful analysis of the productive capacity of the land after reclamation, the cost of reclaiming the land, the market demand for crops best adapted to the region in question, and the comparative advantages of producing such crops in different undeveloped areas.

Drainable Land

Of the approximate total area of land in the United States that is too wet for cultivation (113,500,000 acres), it has been estimated that 91,500,000 acres will be suitable for crops after reclamation. This is 22.1 per cent of the area of the present crop acreage of the United States. Most of the undrained land lies east of the hundredth

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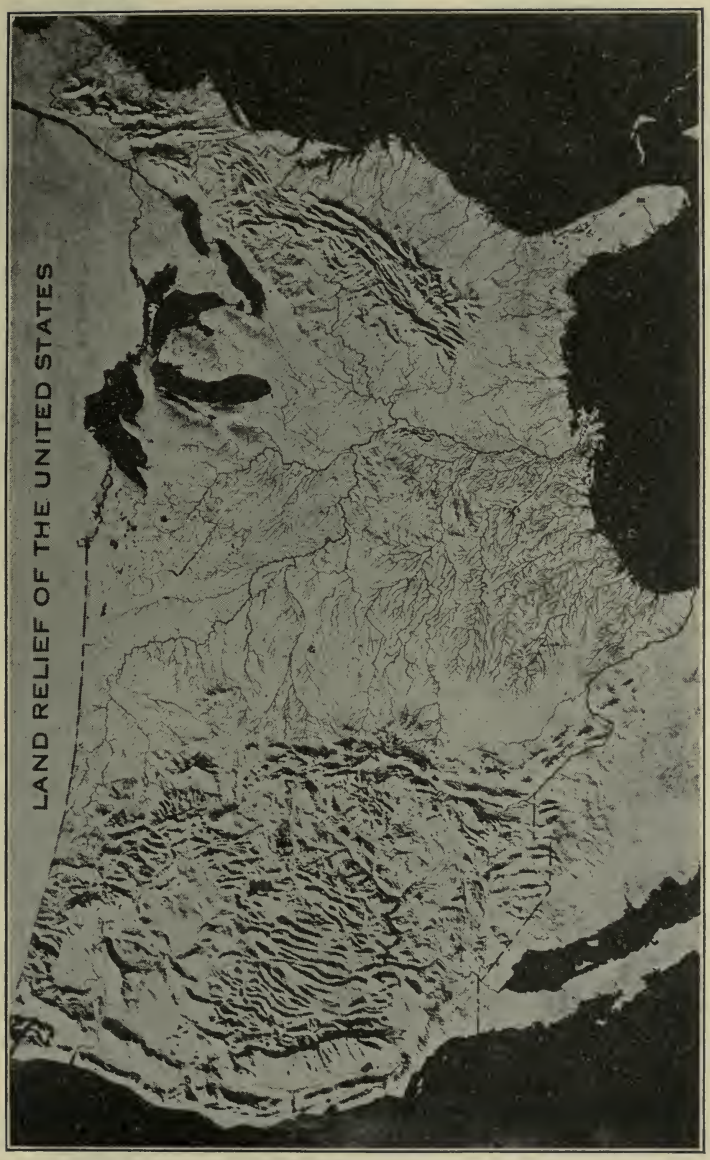

FIGURE 5.—THE TOPOGRAPHY OF THE UNITED STATES IS SHOWN IN A GENERALIZED WAY

The mountainous character of the western regions is clearly indicated; but the map fails to show the high altitude of much of the West, particularly of a large portion of the grazing and irrigated crops region. Owing to the altitude, this region has a much cooler climate than have corresponding latitudes in the East. The vast expanse of the Mississippi Valley, with its level-to-rolling surface, except for the Ozark uplift in the lower central portion, should be especially noted. This is a photograph of a relief model of the United States supplied by the United States Geological Survey, and is used in A Graphic Summary of American Agriculture (*3, p. 7*).

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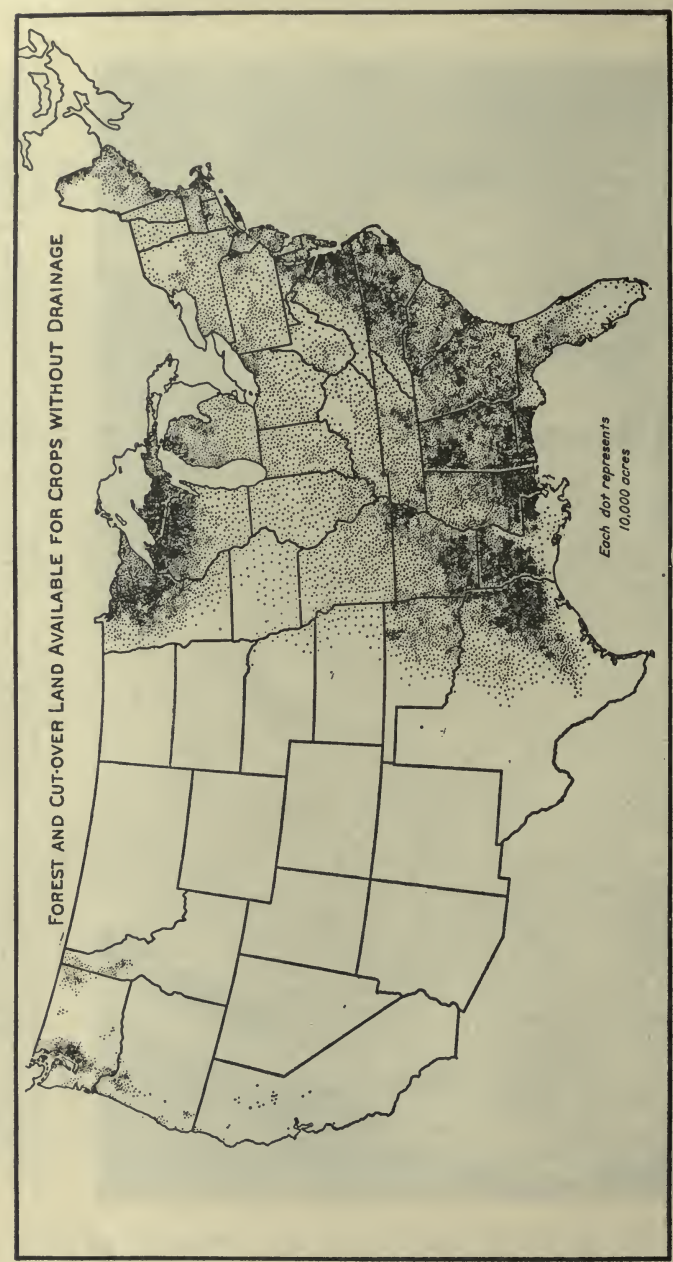

FIGURE 6.—Approximate location and extent of forest and cut-over land available for crops without drainage. In addition there are large areas of forest and cut-over lands which need drainage and clearing before crops can be produced. The map is based on information gathered by the Soil Survey and descriptive data in the General Land Office survey records, and was prepared by F. J. Marschner, Division of Land Economics. Each dot represents 10,000 acres (*15, p. 420*)

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meridian. (Fig. 7.) The largest areas are found in the cut-over areas of Michigan, Wisconsin, and Minnesota, and along the Atlantic coast and the Gulf of Mexico from Virginia to south Texas and up the Mississippi River to southeastern Missouri.

The area may be roughly classified as tidal flats and seasonally wet prairies located along the Atlantic and Gulf coasts; river-flood plains located principally in the valley bottoms of the rivers flowing across the Atlantic coastal plain and along the Mississippi and its tributaries; the Everglades in Florida; and the glacial marshes, and muck and peat bogs in the Great Lakes States. With the exception of the Florida Everglades, the wet prairie lands of southern Louisiana and Texas, and many of the peat bogs of the Northern States, nearly all of the large tracts of unsettled, unreclaimed lands needing drainage are timbered lands.

Clearing land of stumps, brush, down logs, and other débris is an expensive operation; it often totals more than the cost of engineering works to drain the land. The fact that the cost of these two operations sometimes aggregate more than the value of the land after it has been reclaimed chiefly accounts for the large areas of undeveloped land within organized drainage districts. Of the total area of land in drainage enterprises in 1929 (*38, Census 1930*), 18.7 per cent (15,767,984 acres) was not in occupied farms and 35.5 per cent (29,980,516 acres) was not planted. (Table 1.)

TABLE 1.—*Total area of land in drainage enterprises and percentages of total area drained, in farms, and not planted, by States, 1929*

State	Land in drainage enterprises			State	Land in drainage enterprises		
	Total	In farms	Not planted		Total	In farms	Not planted
	Acres	*Per cent*	*Per cent*		*Acres*	*Per cent*	*Per cent*
Arizona	318,931	95.6	12.8	Nevada	162,980	95.4	31.6
Arkansas	4,631,155	63.5	47.6	New Mexico	176,292	85.9	22.0
California	2,233,714	90.6	19.6	North Carolina	679,236	48.7	60.6
Colorado	366,719	83.4	25.0	North Dakota	1,094,142	100.0	16.9
Florida	5,954,934	6.7	96.4	Ohio	8,165,494	99.6	16.7
Georgia	84,255	75.8	56.0	Oklahoma	170,158	96.3	20.1
Idaho	375,464	96.5	10.9	Oregon	211,182	69.4	44.6
Illinois	5,032,682	99.5	15.6	South Carolina	208,249	45.5	70.4
Indiana	10,214,014	99.4	17.2	South Dakota	697,758	98.1	18.7
Iowa	6,137,649	99.5	12.4	Tennessee	593,560	69.7	64.2
Kansas	257,169	98.7	14.6	Texas	2,883,356	65.7	55.7
Kentucky	585,625	88.0	45.3	Utah	156,052	70.2	42.1
Louisiana	3,655,483	70.3	50.1	Virginia	15,042	37.9	68.4
Michigan	9,180,851	96.1	29.6	Washington	367,242	95.8	15.6
Minnesota	11,474,683	76.5	48.4	Wisconsin	892,713	64.4	60.7
Mississippi	2,988,496	70.0	39.7	Wyoming	245,703	76.6	33.7
Missouri	3,150,022	77.1	34.4				
Montana	167,629	90.0	31.8	United States	84,408,093	81.3	35.5
Nebraska	879,459	98.3	15.5				

Based on Bureau of the Census reports, 1930 (*38*).

The existence of a large area of land assessed for drainage benefits but which is not improved and yields no income for other purposes in any drainage or other improvement district, creates a condition more than likely to result in financially embarrassed and sometimes in defunct enterprises. In a study of drainage districts in the South (*25, p. 48*) it was found on the basis of the rate of development between 1920 and 1926 that an average of 40 years would be required to bring under cultivation the unproductive land in organized dis-

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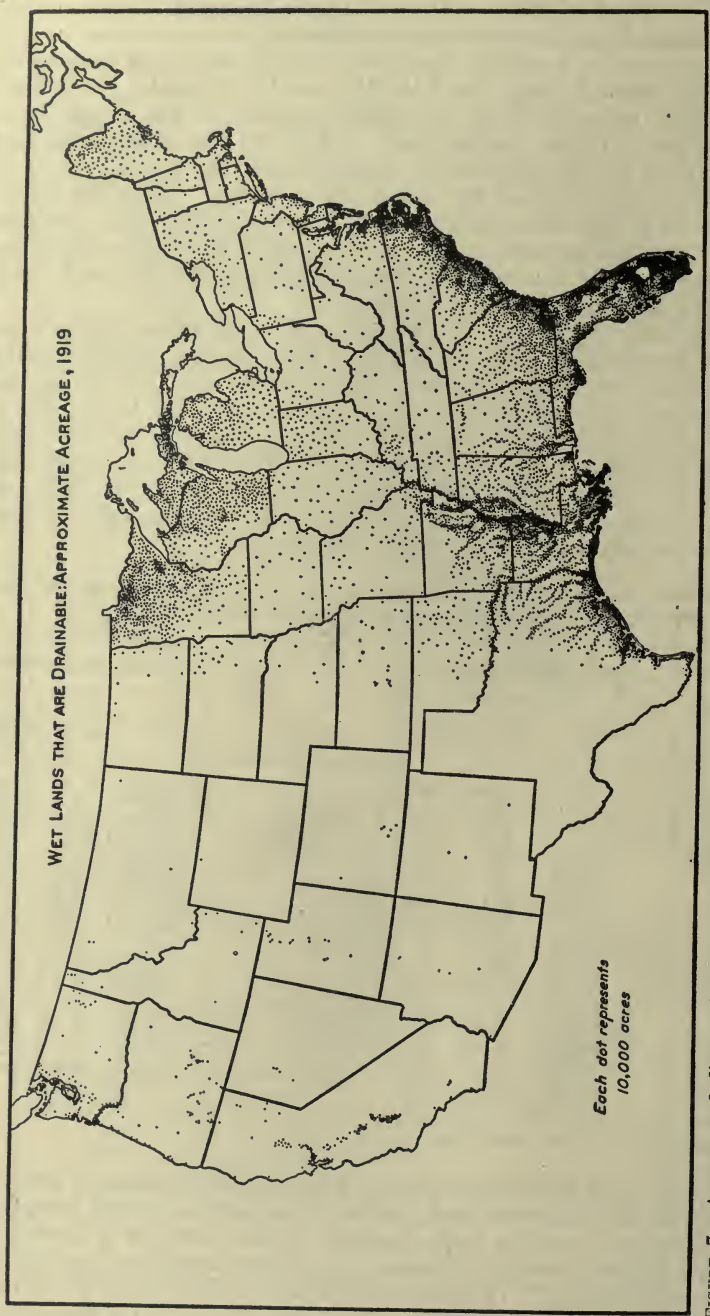

FIGURE 7.—Acreage and distribution of wet, swamp, and overflowed lands unfit for crops without drainage were approximated in 1919. Estimates as of a later date are not available. Two-thirds of the land unfit for cultivation without drainage is in the Southern States, and one-half of the remainder is in the three Lake States. Nearly all of the wet land in the South, except the Florida Everglades and prairies, tidal marsh, and Gulf coastal prairies is forested, and requires both drainage and clearing, but much of the wet land in the Lakes States consists of unforested peat bogs. (Misc. Pub. 105 (*3, p. 26*))

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tricts. Many of these districts were in financial difficulties and the study indicated that more profitable agriculture is necessary to enable these districts to maintain their existing capitalization. Evidence presented by drainage experts representing various parts of the country before the House Committee on Irrigation and Reclamation points out emphatically that these conditions still prevail in many of the districts in the United States (*37*).

Since large areas in organized districts have not been in demand for agricultural use it is evident that careful planning should govern the organization of such districts. The capacity of the land to meet its economic obligations must be ascertained and existing bonded indebtedness adjusted accordingly. Until such procedure is adopted the establishment of profitable farms in drainage districts will be handicapped seriously.

Irrigable Land

A large proportion of the land lying east of the Sierra Nevada and Cascade ranges and west of the one hundred and fourth meridian (which is practically the eastern boundary of Montana, Wyoming, Colorado, and New Mexico) receives a rainfall too light for ordinary production of crops. (Fig. 2.) Although the major portion of this area is mountainous or desert waste, in so far as intensive crop production is concerned, there are many broad and fertile river valleys, basins among the mountains, lake beds or lake margins, and other places, that are or can be irrigated. Of the irrigable acres in irrigation enterprises in 1930, only 63.9 per cent were irrigated, although engineering works were capable of providing water for 85.3 per cent of the total (*38*). In other words, in addition to 4,497,580 acres for which engineering works were not ready to supply water in 1930 there were 6,554,346 nonirrigated acres which engineering works were prepared to irrigate, but which were not employed for purposes of irrigated farming. The distribution of these acreages among the different States is shown in Table 2.

Table 2.—*Irrigable and irrigated land in irrigation enterprises, by States*

State	Irrigable land in irrigation enterprises			
	Total, 1930	Irrigated in 1929	Land enterprises capable of irrigating in 1930	Not irrigated in 1929
	Acres	*Acres*	*Acres*	*Per cent*
Arizona	1,085,627	575,590	824,152	47.0
Arkansas	225,992	151,787	209,942	32.8
California	8,075,895	4,746,632	6,815,250	41.2
Colorado	4,528,251	3,393,619	4,078,712	25.1
Idaho	2,814,048	2,181,250	2,617,021	22.5
Kansas	95,719	71,290	83,583	25.5
Louisiana	850,401	450,901	795,165	47.0
Montana	2,622,423	1,594,912	2,276,000	39.2
Nebraska	763,039	532,617	703,641	30.2
Nevada	983,717	486,648	736,249	50.5
New Mexico	741,245	527,033	656,669	28.9
North Dakota	24,860	9,392	24,006	62.2
Oklahoma	7,344	1,573	7,331	78.6
Oregon	1,478,128	898,713	1,158,210	39.2
South Dakota	122,510	67,107	109,550	45.2
Texas	1,566,876	798,917	1,177,415	49.0
Utah	1,739,869	1,324,125	1,542,475	23.9
Washington	915,379	499,283	631,511	45.5
Wyoming	1,958,147	1,236,155	1,655,008	36.9
United States	30,599,470	19,547,544	26,101,890	36.1

Bureau of the Census, 1930 (*38*).

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Irrigation enterprises may be divided into three classes: Private, State, or Federal projects. The Bureau of Reclamation, United States Department of the Interior, has charge of Federal projects. The United States reclamation act (act of June 17, 1902) provides for Government construction of irrigation works, with provisions for repayment of the cost of construction over a period of years up to 40 years without interest on deferred payments.

The prospective irrigation farmer is confronted with problems somewhat similar to those described for drainage districts. Many irrigation districts are financially sound, but financially embarrassed districts are not uncommon. The organization of many districts was promoted before they were justified by demand for crops. The inclusion of unproductive land in addition to more land than could be irrigated adequately with the available water, poor engineering works, excessive charges by promoters of the enterprises, and many less important factors contribute toward the failure of such enterprises.[3]

Recapitalization of the enterprise on the basis of a conservative estimate of the earning capacity of productive land is essential on many projects to insure the establishment of profitable farming enterprises. In many instances such recapitalization may mean partial cancellation of existing obligations. Officials in several States have taken steps to facilitate such refinancing programs. With respect to Federal projects, Congress has passed a series of relief acts, particularly during the last decade. Among these the omnibus reclamation act (act of May 25, 1926) is the most important. By this act the period of repayment of construction charges was increased, at the discretion of the Secretary of the Interior, to 40 years. Rapidly mounting delinquent payments due on construction charges were reduced or wiped out. Subsection K of H. R. 9559 (*43, p. 703*) provides for relief to irrigation farmers in still another way:

> * * * on each existing project where, in the opinion of the Secretary, it appears that on account of lack of fertility in the soil, an inadequate water supply, or other physical causes, settlers are unable to pay construction costs, or whenever it appears that the cost of any reclamation project by reason of error or mistake or for any cause has been apportioned or charged upon a smaller area of land than the total area of land under said project, the Secretary is authorized to undertake a comprehensive and detailed survey to ascertain all pertinent facts, and report in each case the result of such survey to the Congress with his recommendations.

In general, the policy of charging off or writing down construction charges is desirable on any project where construction costs are in excess of the carrying capacity of the land. In fact, until the overcapitalization in each project is eliminated by some method, the project will not be sound financially. Prospective irrigation farmers can not afford to buy land in any public or private irrigation enterprise that is not economically sound. This is particularly true of those projects on which farmers are jointly responsible for meeting the construction and other costs without regard to default in payment of charges against any individual farm unit or tract of irrigable land.

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[3] These and other causes of failure along with a discussion of various financial and engineering aspects of irrigation districts are discussed in greater detail by Hutchins (*20*).

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Climate, crop possibilities, and cost of irrigating land are important factors that are often discounted. The soil is usually fertile. A fertile soil, the application of water to growing crops at just the right time and in the quantity needed, and the preponderance of clear days and even temperature make a combination of factors which usually results in higher yields per acre than is obtained from fields depending upon rainfall. These factors, when combined with a comparatively low cost for engineering works necessary to irrigate the land, have resulted in the establishment of prosperous farming enterprises on what was previously desert or other barren waste land.

The vision of high yields without regard to cost, however, usually leads to misfortune. Economic surveys of reclamation projects made by a committee which included "practical irrigators, economic experts from agricultural colleges, and representatives of the Bureau of Reclamation" led to the conclusion that in addition to cost of construction of reservoirs and main canals, from $5,000 to $10,000 must be spent to provide the permanent improvements and equipment necessary for an 80-acre farm (*26, p. 1208*).

Dry Farming and Grazing Land

Irrigation farming and grazing and (in certain areas west of the one hundredth meridian) dry farming are intermingled. In many parts of the Western States river valleys are or can be irrigated, a few higher benches and terraces are usable for dry-farming purposes, and the remainder of the land that is suitable for any agricultural purpose is usable for grazing purposes.

The dry-farming territory may be divided into three areas, according to seasonal rainfall: (1) The Great Plains area, with the major portion of the precipitation in June, July, and August; (2) the intermountain area or high interior plateaus, mostly the northern portion, with late winter and early spring rains; and (3) the Pacific coast area with winter rains. Assuming a productive soil and topography favorable to the use of large-scale machinery, dry farming is limited by the precipitation at particular times of the year, the amount of evaporation, and the prices obtainable for crops grown. Roughly, dry farming is not practicable in areas having less than 9 or 10 inches in central Washington and northwestern Montana to 20 inches in western Texas; nor is it necessary where there is more than 15 to 25 inches annual precipitation, depending on the rate of evaporation, the character of the rainfall, and the soil.

Dry farming is a business that requires operators with considerable capital and technical skill. The capital is needed to tide over dry seasons and to operate areas sufficiently large to return a livelihood. If moisture is not conserved in the soil, and if crops not adapted to the conditions of the growing season are tried, failure is likely. Hundreds of abandoned farms scattered throughout the dry-farming region demonstrate that fact.

The grazing value of this territory depends upon the supply of drinking water for the stock, carrying capacity of the range, length of the grazing season, and possibility of growing hay and forage. The Department of the Interior when making designations for enlarged and stock-raising homesteads found the highest carrying capacity in the Great Plains, where the land will carry from 18 to

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80 head of cattle per section, to be from six months to an entire year.[4] Certain parts of Nevada, southwest Arizona, and southeast California have only a scattering of alkaline plants and will not support enough cattle per unit of land to be practicably usable for grazing. There are numerous areas in the Rocky Mountain and Pacific coast regions that have little value for grazing, but the percentage is small in proportion to the total. The very best lands among the mountains have a carrying capacity of 30 to 65 head per section.

The formulation of public policy based on a careful analysis of the potentialities of using land for grazing would eliminate much of the social loss resulting from misdirected efforts of private users to utilize these lands for unsuitable purposes.

OWNERSHIP OF UNDEVELOPED LAND

With few exceptions, all lands physically capable of producing crops, which are not now so employed, are in private ownership. On June 30, 1930, there were 178,979,446 acres (*40, p. 14*) of Federal lands subject to entry under the homestead and all other applicable land laws, but these lands have little or no value for crop production. Many are located in the deserts and other arid sections of the West. Figure 8 and Table 3 show the distribution of these lands by States. Part of this immense acreage is practically useless for any purpose. The best use for a little of it is for forests and watershed protection. Some of it is usable for certain grazing purposes, the carrying capacity of these lands having been estimated to vary from 25 to 75 acres per head of cattle.

Occasionally, there are restorations to entry of lands that might be suitable for farming and which, for some reason, have been withdrawn from entry. Although the various land laws under which public land is open to homestead entry have outlived their usefulness, they are still in force.

TABLE 3.—*Area of vacant, unappropriated, and unreserved public lands on July 1, 1930*

State	Surveyed	Unsurveyed	Total	State	Surveyed	Unsurveyed	Total
	Acres	*Acres*	*Acres*		*Acres*	*Acres*	*Acres*
Arizona	8, 084, 880	7, 096, 000	15, 180, 880	New Mexico	14, 316, 481	1, 347, 640	15, 664, 121
Arkansas	190, 969		190, 969	North Dakota	146, 505		146, 505
California	11, 284, 395	5, 339, 093	16, 623, 488	Oregon	12, 976, 725	92, 411	13, 069, 136
Colorado	6, 825, 425	1, 202, 043	8, 027, 468	South Dakota	439, 880		439, 880
Florida	12, 245	6, 652	18, 897	Utah	12, 378, 068	11, 503, 377	23, 881, 445
Idaho	8, 765, 491	1, 852, 479	10, 617, 970	Washington	906, 382	14, 202	920, 584
Minnesota	189, 845		189, 845	Wyoming	15, 185, 722	743, 738	15, 929, 460
Montana	6, 510, 937	90, 740	6, 601, 677				
Nebraska	22, 628		22, 628	United States	128, 301, 266	50, 678, 180	178,979,446
Nevada	30, 064, 688	21, 389, 805	51, 454, 493				

U. S. Dept. Interior, Gen. Land Off. Circ. 1230 (*40, p. 14*).

In addition to Federal lands open for homestead entry certain Indian lands may be purchased or leased through Federal agencies.[5]

In general, the lands of any adult Indian to whom a patent has been issued are subject to sale or lease under rules and regulations

[4] See pp. 68 to 78 for further discussion of the land classification.

[5] The commissioner of Indian Affairs, Washington, D. C., and the superintendent of the Five Civilized Tribes, Muskogee, Okla., are sources of information concerning Indian lands held for sale or lease. (See Annual Report, Department of the Interior, Indian Affairs, 1930.)

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prescribed by the Secretary of the Interior. A sale is authorized only when it appears to be for the best interest of the Indian who petitions for the right to sell. As a rule three sales are held each year and the lands offered range in quality from good farming land to rough or barren grazing land. No compilation of lands held for sale or lease is available but the unallotted area in Indian

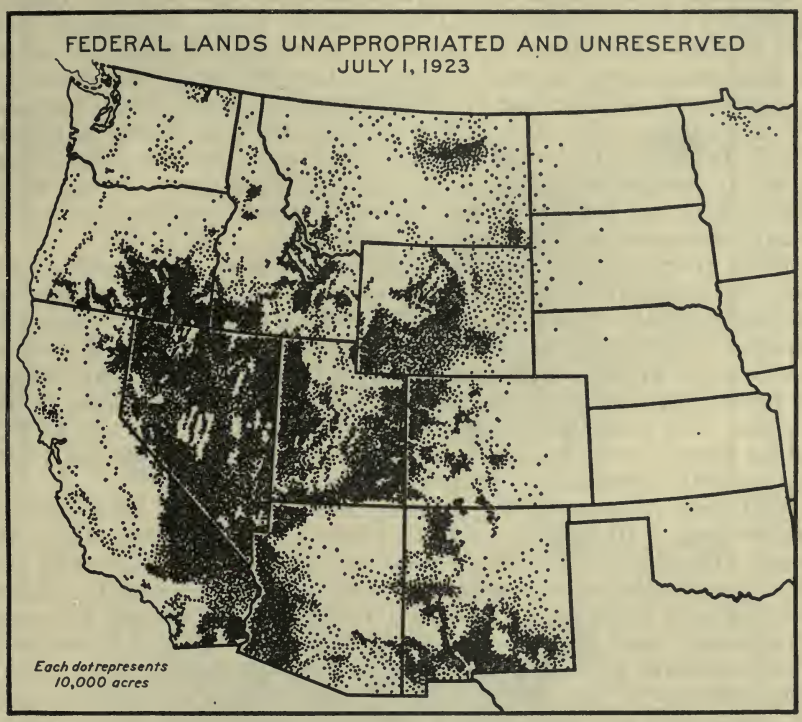

FIGURE 8.—Approximate location and extent, in 1923, of the public domain; that is, the area not already appropriated or reserved for specific purposes. The only important change since the map was made is an increase of about 8,000,000 acres previously entered but never patented nor withdrawn from entry and subsequently returned to the public domain. (U. S. Dept. Agr. Misc. Pub. 97, (*14, p. 48*))

reservations which may be subject to sale at various dates in the future totals 32,014,946 acres (*41*). The distribution of this acreage in the various States is shown in Table 4.

TABLE 4.—*Unallotted area of land in Indian reservations, by States, June 30, 1929*

State	Unallotted Indian land	State	Unallotted Indian land	State	Unallotted Indian land
	Acres		*Acres*		*Acres*
Arizona	20,290,151.68	Montana	770,135.08	South Dakota	263,110.87
California	495,330.93	Nebraska	7,405.00	Utah	340,680.00
Colorado	396,143.00	Nevada	832,182.00	Washington	854,901.23
Florida	26,741.00	New Mexico	3,534,850.00	Wisconsin	273,584.76
Idaho	57,359.00	New York	87,677.00	Wyoming	1,997,000.00
Iowa	3,480.00	North Carolina	63,211.00		
Kansas	1,183.00	North Dakota	1,107.00	United States	32,014,945.65
Michigan	155.00	Oklahoma	38,956.66		
Minnesota	555,726.44	Oregon	1,123,875.00		

U. S. Dept. Interior, Off. of Indian Affairs, General Data Concerning Indian Reservations (*41*).

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Until public-land laws are revised and a constructive public policy is adopted to utilize these semiarid and arid lands for the most suitable purposes, the statement made many years ago that homesteading is betting "Uncle Sam" a filing fee that the settler can live on his claim long enough to prove up will continue to epitomize our policy.

Accurate information is not available as to the best use for the 56,792,978 acres of State-owned land subject to sale or lease in 1930. But as these lands have not attracted purchasers and as the major portion of the total acreage is west of the one hundredth meridian, it seems evident that they are not, in general, particularly valuable for cultivation. The distribution of these lands is shown in Figure 9 and Table 5. The table presents a summary of the policies followed by the several States in disposing of State land. In substance State offices are authorized and directed to sell or lease land under conditions prescribed by the State legislature.

With practically no available agricultural land in Federal ownership and a relatively small acreage of such land in State ownership, substantially all of the remaining 600,000,000 acres of land physically capable of producing crops, but not now so employed, are in private ownership. What proportion of the potential agricultural acreage in private ownership is on the market to be sold or leased is unknown. Nor is there any available record of the proportion of privately owned lands held for sale or lease which are physically and economically unsuited for crop production.

Railroads are possibly the largest private owners of land held for sale or lease. In 1928 the area of land so owned totaled 22,325,885 acres. The distribution of these lands is indicated in Figure 10 and the acreage held for sale or lease in the various States by the different railroads is shown in Table 6. The class of land and the terms of sale and lease are summarized in this table. Many of the railroads maintain agricultural and immigration departments to induce settlers to buy or lease their privately owned lands and to encourage the settlement and development of other lands within the territory they serve.

In addition to the railroads, there are innumerable private colonization, land-settlement, and miscellaneous agencies which own land and are interested in selling it. From a practical point of view these private agencies control most of the remaining land that is physically capable of crop production. Most of this land is economically submarginal because of low fertility, remote location, or the necessity of making heavy expenditure for clearing, drainage, irrigation, or soil improvement. Since only a small proportion of this land is likely to be required to meet the needs of population increase, its existence constitutes a serious problem. The competition between private agencies to dispose of such land, in spite of the fact that no more farm land is needed now, results in wasteful misuse of natural and human resources. Furthermore, until changes in public policy necessary to effect an economical utilization of land resources materialize, the vast acreage of submarginal land remains a constant menace to the prosperity and welfare of uninformed purchasers of land for farming purposes.

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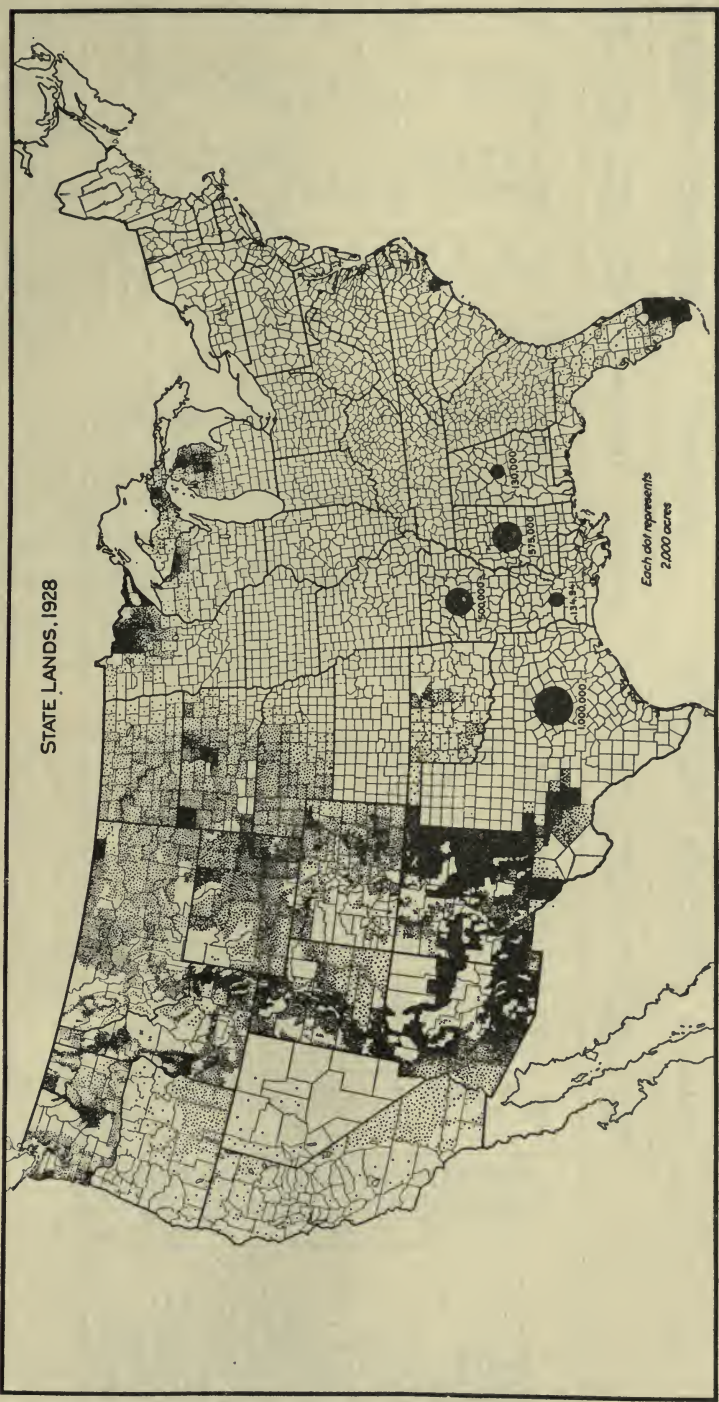

FIGURE 9.—Distribution of State land held for sale or lease by State agencies listed in the Appendix. For Texas, Arkansas, Louisiana, Mississippi, and Oklahoma, the statistics are only for the State as a whole. (Based on data obtained from State reports and correspondence with State officials, by F. J. Marschner, in 1928)

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TABLE 5.—*Acreage and terms of sale and lease of State-owned lands*

State	Total area	Terms of sale										Terms of lease			
		Maximum unit		Minimum selling price per acre [1]		Initial payment as percentage of sale price		Credit on balance				Minimum annual rental per acre		Maximum length of lease	
		Grazing land	Agricultural land	Grazing land	Agricultural land	Grazing land	Agricultural land	Grazing land		Agricultural land		Grazing land	Agricultural land	Grazing land	Agricultural land
	Acres	*Acres*	*Acres*	*Dollars*	*Dollars*	*Per cent*	*Per cent*	*Years*	*Per cent interest*	*Years*	*Per cent interest*	*Dollars*	*Dollars*	*Years*	*Years*
Alabama [2]	130,000	(3)	(3)	(4)	(4)	(5)	(5)	(5)	(5)	(5)	(5)	(4)	(4)	5	5
Arizona	8,939,757	640	160	3.00	25.00	5	[6] 5	38	5	38	5	0.03	0.62	5	5
Arkansas	1,500,000	(3)	(3)	1.00	1.00	100	100	0	0	0	0	(7)	(7)	(7)	(7)
California	738,169	640	320	(4)	(4)	10	10	9	6	9	6	(4)	(4)	10	10
Colorado	3,061,464	640	640	(4)	(4)	10	10	18	6	18	6	[8] .08	[8] .50	5	5
Florida	1,236,086	[9] 320	[9] 320	(4)	(4)	(10)	(10)	(10)	(10)	(10)	(10)	(4)	(4)	1	1
Idaho	3,205,058	[11] 320	[11] 320	10.00	10.00	10	10	40	6	40	6	.07	.50	5	5
Louisiana [12]	134,941														
Michigan	1,959,337	240	240	(4)	(4)	100	100	0	0	0	0	(13)	(13)	(13)	(13)
Minnesota	2,056,273	(14)	320	(14)	(14)	(14)	15	(14)	(14)	40	4	(14)	(14)	(14)	(14)
Mississippi [15]	575,000														
Montana	4,577,880	640	160	10.00	10.00	10	10	33	5	33	5	.06	(4)	5	5
Nebraska	1,591,656	640	(16)	(4)	(16)	25	(16)	10	6	(16)	(16)	(4)	(16)	25	(16)
Nevada	61,353	960	960	1.25	2.50	20	20	50	6	50	6	(7)	(7)	(7)	(7)
New Mexico	9,402,000	(3)	(3)	3.00	3.00	5	5	30	4	30	4	.03	.10	5	5
North Carolina [17]	106,000	(3)	(3)	(3)	(3)	100	100	0	0	0	0	(3)	(3)	(3)	(3)
North Dakota	1,442,476	640	160	10.00	10.00	20	20	20	6	20	6	.09	[18] .50	5	3
Oklahoma [19]	691,395			7.00	20.00	5	5	40	5	40	5	.20	.70	5	5
Oregon	661,594	320	320	2.50	2.50	20	20	5	6–8	5	6–8	.10	.10	10	10
South Dakota	2,782,626			(4)	(4)	20	20	25	5	20	5	(3)	(3)	5	5
Texas [20]	3,000,240														
Utah	2,841,132			2.50	2.50	10	10	20	5	20	5	.05	.50	12	12
Washington	2,161,849	640	160	10.00	10.00	[21] 10	[21] 10	[21] 10	[21] 6	[21] 10	[21] 6	(4)	(4)	5	5
Wisconsin [22]	352,454														
Wyoming	3,584,238	(3)	(3)	10.00	10.00	10	10	30	4	30	4	(4)	(4)	5	5
United States	56,792,978														

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Data obtained from State reports and correspondence with State officials between 1929 and 1931.

[1] Minimum prices given are set by legislation. In certain States this minimum is increased through special appraisal by State officials and/or by sale to highest bidder at public auction.

[2] Most of land is classed as mineral land which may be leased for mineral purposes for 20-year periods or purchased at appraisal price. Land may be leased for grazing and agricultural purposes for 5-year periods.

[3] No stipulated limit.

[4] Appraisal.

[5] Variable.

[6] Except in case of improved property when 10 per cent of purchase price is required as initial payment; 15 per cent in 30 days; balance in 5 years payable annually with 6 per cent interest.

[7] No lands leased.

[8] Minimum leased rentals: 8 cents per acre per year for grazing land without water, 12 cents with water; agricultural land from 50 to 75 cents.

[9] More than 320 acres may be purchased by advertising the lands for 30 days in some newspaper published in the county or counties in which lands are located.

[10] Credit terms obtainable: 20 semiannual payments with initial payment of 5 per cent; 10 annual payments with initial payments of 10 per cent; 5 semiannual or 5 quarterly payments with initial payments of 20 per cent.

[11] Public school lands, maximum 320; university lands, 160 acres.

[12] Lands withdrawn from market except for oil and gas leasing purposes.

[13] Land may be homesteaded through State conservation department. Clear title is obtainable after five years of continuous occupancy. Land is not leased.

[14] A few selected 40's partially improved by the State are called improved State lands. These are sold at auction to settlers, who must agree in writing to establish residence, cultivate, and improve them within 18 months, costs of improvements to be paid within 5 years. Camp and summer cottage sites on State-owned lake-front land may be leased for 10-year periods at an annual rental of $12. No other land is leased and no land is classed as grazing land.

[15] Regulations relative to the sale and lease of lands are not available.

[16] All lands are classified as grazing lands.

[17] Mostly swamp land unfit for farming.

[18] Minimum rental for agricultural land: 50 cents per acre in western counties and 75 cents per acre in eastern counties.

[19] State-owned lands having oil and gas possibilities have been withdrawn from market except for oil and gas leasing purposes.

[20] No school land sold between 1925 and the fall of 1930; no information available relative to the sale or lease of land in 1930.

[21] A second credit plan provides for an initial payment of 5 per cent of purchase price. No further payments are required on principal until the eleventh year. Four per cent interest is charged on deferred payments. The balance after the eleventh year is payable in 10 annual installments with interest at 6 per cent on deferred payments.

[22] No State lands sold since 1913. Lake frontage may be leased. Timber on remaining land is sold.

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TABLE 6.—*Location, areas, and general terms of sale of railroad lands available for agricultural purposes in 1928, by companies and States in which lands are located*

Company	State	Area	Terms of sale			
			Price per acre	Initial payments as percentage of price sale	Credit on balance	
					Years	Rate of interest
		Acres	*Dollars*	*Per cent*	*Number*	*Per cent*
Northern Pacific Railway	Idaho	28,675	1.75–20	16⅔	5	6
	Minnesota	46,901				
	Montana	4,553,008				
	North Dakota	189,614				
	Oregon	85,782				
	Washington	340,227				
	Wisconsin	1,925				
	Wyoming	35,516				
Southern Pacific	California	4,738,488	.50–150	10	10–19	--------
	Nevada	4,116,573				
	Utah	615,564				
Atchison, Topeka & Santa Fe Railway system	Arizona	2,721,447	(1)	12½	7	6
	California	1,600				
	Kansas	10,556				
	New Mexico	2,006,509				
	Texas	79,198				
Union Pacific system	Colorado	20,226	--------	--------	--------	--------
	Kansas	2,105				
	Nebraska	10,317				
	Utah	12,490				
	Wyoming	785,853				
Chicago, Rock Island & Pacific Railway	Minnesota	69,911	2.00–10	--------	10–15	6
Duluth and Iron Range Railroad	Minnesota	416,211	2.00–10	--------	10–15	6
Minnesota, St. Paul & Sault Sainte Marie Railway.	Wisconsin	350,000	5.00–15	25	3	6
Florida East Coast Railroad	Florida	348,976	25.00–250	25	2–3	6–8
Missouri Pacific Railroad	Arkansas	318,220	7.50–15	25	3	6
Seaboard Air Line Railway	Florida	172,000	10.00–300	20	4–5	6
Great Northern Railway	Minnesota	92,070	3.00–20	10	4	6
Mobile & Ohio Railroad	Alabama	18,626	--------	25	1–3	6
	Mississippi	56,698				
Chicago, St. Paul, Minnesota & Omaha Railway.	Wisconsin	26,979	7.00–40	33⅓	4	6
Chicago and North Western Railway	Michigan	50,000	3.50–5	100	0	0
Nashville, Chattanooga & St. Louis Railway.	Tennessee	3,620	3.00–20	25	--------	--------

Information obtained from railroad officials.

[1] No average sale price of land in all States is available. Prices in New Mexico range from $1 to $4; in Texas from $15 to $20; and in California the average price is reported as $250 per acre.

Private owners can not be expected to remove their land from the farm-land market until the tax laws are modified, particularly with respect to the taxation of undeveloped real estate and until new public policies of land utilization are adopted. In fact, in many States undeveloped land is taxed on a basis of its estimated value for agricultural purposes, apparently almost without regard to its demand for that use. Consequently large areas of land revert to public ownership through tax delinquency.

Owners of undeveloped land subject to sale, who continue to carry the load of taxation, increasingly try to dispose of their holdings. Some active land-settlement and colonization companies are doing constructive work, but the results of a survey (fall of 1929–spring of 1930) of the "literature" used by and practices of 1,258 of these agencies operating in all parts of the United States indicated that a large number are preying on the public in general and the unin-

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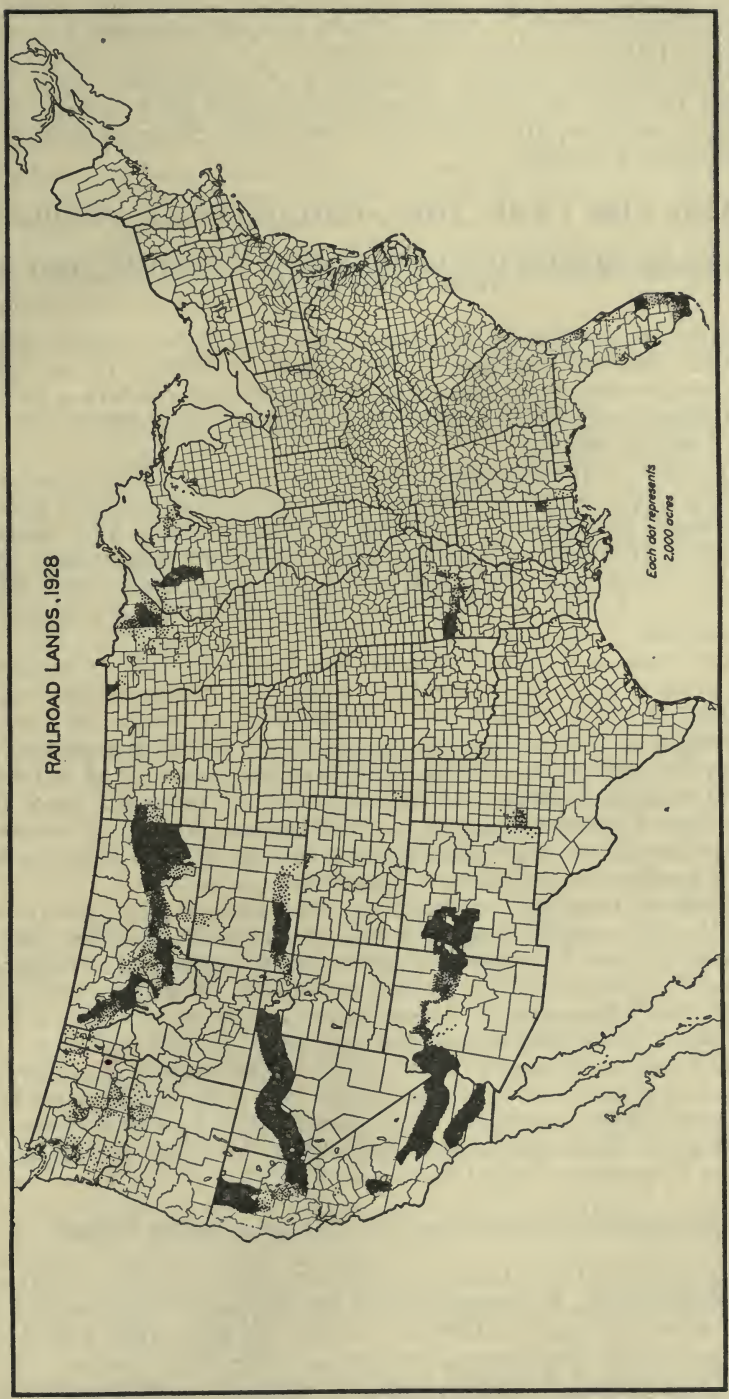

FIGURE 10.—Practically all of the railroad lands are located in the arid and semiarid western half of the United States where dry farming, irrigation farming, and grazing prevail. (Data obtained through correspondence with railroad officials by F. J. Marschner, Division of Land Economics, U. S. Dept. of Agr., 1928)

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formed prospective settler in particular. Many companies in interstate business manage to avoid specific misrepresentation by using ambiguous phrases and half truths, and by making skillful omissions from their glowing accounts of profits to all purchasers. The fact that 46.7 per cent of these companies are selling land in more than one State indicates the need for coordinated State and Federal land-utilization policies.

DEMAND FOR LAND FOR AGRICULTURAL PURPOSES

POPULATION TRENDS AND ESTIMATES OF ECONOMIC NEED FOR MORE FARM LAND

Students of population statistics[6] have concluded within recent years that, barring increases in birth rates or changes in immigration laws permitting immigration increases, the population of the United States will reach a stationary stage at about 150,000,000 or less by 1960 or before.

With approximately 600,000,000 acres of land physically capable of producing crops, which are not now so employed, and with a potential increase in population of only a comparatively few million people, the problems of land utilization become increasingly important. It has been estimated (*15, p. 494*) that only about 373,000,000 acres of crop land would be needed to supply a population of 150,000,000.

On this basis less than 50,000,000 acres of crop land in addition to our present crop acreage will be needed to supply a stationary population of about 150,000,000. The possible reversion of present crop acreage to some other use because of erosion and depletion of fertility, the possible changes in tariff laws, the quantity of different kinds of foodstuffs that will be exported or imported, and the uncertainty of future changes in consumption and in production technic, make an exact prediction as to acreage of new land needed for crop production exceedingly hazardous.

It is difficult to avoid the conclusion that there is now, and probably will be for many years to come, an economic need for only a comparatively small increase in net crop acreage. This suggests the need for conservatism in the expansion of agriculture. In many parts of the country the problem might resolve itself into one of effecting more economical use of land already in farms. In other parts, abandonment of submarginal farms and a resettlement program in general may be the result. In still others, favorable climatic and other conditions may permit considerable increase in the acreage of farm land at the expense of land now in farms in areas less favorably situated.

MOVEMENTS OF POPULATION TO AND FROM FARMS

The expansion of our farm area between 1910 and 1920 (increase of 77,085,390 acres) as compared with an increase of approximately half as much acreage (40,206,551 acres) between 1900 and 1910

[6] W. I. Thompson and P. K. Whelpton of the Scripps' Institute of Population Research; Louis I. Dublin, the Metropolitan Life Insurance Co., New York City; Robert Kuczynski, Brookings Institute, Washington, D. C., and O. E. Baker, U. S. Department of Agriculture.

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was followed by an increase of 30,887,301 acres in farms between 1920 and 1930 (*38*). That a large part of this expansion was not economically justified is suggested in the long continuance of low prices for agricultural crops, and the larger movement of people from farms to city than from cities to farms, between 1920 and 1930. Annual estimates of movements to and from farms since 1922 are available. (Table 7.) The peak loss to farms occurred in 1922 when 1,120,000 more people moved to cities than from cities to farms. There was almost as large a net loss in 1926, but a definite check in the movement seems to have taken place during 1930 when the net loss to farms was only 151,000 people, probably largely because of urban unemployment.

TABLE 7.—*Movement to and from farms in the United States, 1922–1931*

Year	Persons leaving farms for cities	Persons arriving at farms from cities	Net movement from farms to cities [1]	Year	Persons leaving farms for cities	Persons arriving at farms from cities	Net movement from farms to cities [1]
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
1922	2,000,000	880,000	1,120,000	1927	1,978,000	1,374,000	604,000
1923	(2)	(2)	(2)	1928	1,923,000	1,347,000	576,000
1924	2,075,000	1,396,000	679,000	1929	1,876,000	1,257,000	619,000
1925	1,900,000	1,066,000	834,000	1930	1,543,000	1,392,000	151,000
1926	2,155,000	1,135,000	1,020,000	1931	1,472,000	1,679,000	−207,000

Estimates made by Division of Farm Population and Rural Life, Bureau of Agricultural Economics, The Agricultural Situation (*13, p. 3*).

[1] Births and deaths not taken into account.
[2] No estimate.

During 1931, 207,000 more people moved from cities to farms than from farms to cities. This was the first year for which figures are available that the movement to farms exceeded the movement to cities. Business depression and heavy unemployment in cities stimulated the countryward trek in spite of the fact that farmers in general experienced as much if not more difficulty in earning a satisfactory income from their farms in 1931 than during the previous decade when the farm to city movement greatly exceeded the opposite flow. The cityward movement left a trail of vacant farmsteads which attracted the unemployed city families in 1931. Many hundreds of farms in the older crop regions had been rendered economically obsolete by boll-weevil invasion, inefficient farm practices, and erosion and loss of soil fertility. The consolidation of farms and the use of large-scale farm machinery and other improved methods of production technic, particularly in wheat and cotton production, probably account for a part of the excess movement from farms to cities previous to 1931. Misinformed and misdirected expansion programs carried on by private and public interests account for a large number of abandoned farms in cut-over regions and other newly developed areas such as drainage, levee, irrigation, and other improvement districts. This is particularly true of expansion programs started during a period of high prices and completed during a period of falling prices.

In general, it might be said that, with a few notable exceptions described in other parts of this bulletin, the State and private land-settlement agencies interested in attracting settlers to their respective

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States have taken little or no account of the suitability of the land for cultivation or of the work required and the capital necessary before the settler could develop his tract of land into a "going concern." Likewise, little or no attention has been paid to selecting the settler on the basis of personal and family qualifications for developing a farm and successfully practicing the type of farming best suited to the area in question. As a consequence, many communities, and in some instances large parts of entire States, were partly developed by settlers who were doomed to failure from the beginning. The continuance of such haphazard land-settlement policies under existing economic conditions means little chance to avoid disaster to the settlers, to the land-selling agencies, and to the communities.

DECREASE IN IMMIGRATION

The prospective supply of potential settlers is much smaller than it was before the immigration laws were modified and the best lands were occupied. Before the great development of industrialism in the United States, a large proportion of the pioneers on farms consisted of foreign immigrants. This condition has changed materially since the beginning of the World War, if the assumption is correct that the immigrants classed as farmers and farm laborers represented a large proportion of all immigrants who went to the farms. The number of farmer and farm-laborer immigrants admitted to this country decreased markedly during the period 1909–10 to 1914–15 and reached the low level of 7,121 in 1917–18. The high point reached since 1914–15 was 54,682 in 1920–21. (Table 8.)

TABLE 8.—*Immigration and emigration of alien farmers and farm laborers, United States, 1909–10 to 1930–31*

Year ended June 30	Aliens admitted	Aliens departed	Net movement (immigrants)	Year ended June 30	Aliens admitted	Aliens departed	Net movement (immigrants)
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
1910	300,538	6,097	294,441	1921	54,682	12,578	42,104
1911	185,712	18,078	167,634	1922	18,205	7,726	10,479
1912	191,818	11,785	180,033	1923	38,408	2,648	35,760
1913	333,285	10,068	323,217	1924	47,812	1,834	45,978
1914	302,495	11,205	291,290	1925	29,897	1,631	28,266
1915	31,241	5,909	25,332	1926	27,110	1,512	25,598
1916	33,090	4,270	28,820	1927	34,022	1,546	32,476
1917	30,092	4,670	25,422	1928	32,934	1,764	31,170
1918	7,121	4,607	2,514	1929	28,158	1,632	26,526
1919	8,345	3,094	5,251	1930	22,111	1,700	20,411
1920	27,449	14,016	13,433	1931	6,165	2,278	3,887

Taken from the annual reports of the Commissioner General of Immigration (*42*) for the years indicated.

No statistics are available to show how many of the farmers and farm laborers actually went to the land. That it is no longer the haven for many of them is suggested by the decrease in foreign-born white farm operators from 669,556 in 1910 to 581,068 in 1920 (*38, p. 295*) and to 474,083 in 1930 (*39, p. 27*). These figures suggest further that the old foreign-born white owners are passing away, retiring, or entering other occupations, and that new foreigners are now taking their places.

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More restrictive immigration barriers and changed industrial and economic conditions during the last decade tend to make the number of qualified prospective settlers more limited than ever before. No one knows how permanent these conditions are. However, on the basis of our present knowledge with respect to the need for increasing our net crop acreage to meet future demands for farm crops, competition between land-selling agencies is likely to increase. A constructive public policy which recognizes the need for making possible the utilization of land for purposes other than agricultural would tend to remove from the farm-land market much of this privately owned land.

PUBLIC LAND-SETTLEMENT POLICIES

In general, the Federal and State settlement policies of the past aimed at getting undeveloped land into farms. Little or no attention was given to the use for which land was best adapted. As long as large areas of good agricultural lands were unoccupied and a heavy demand for farm land existed, the evils of these haphazard settlement policies were not so obvious as they are under present conditions. The American agricultural experience, generation after generation, has been that land values rise and that a poor man could buy land cheaply and see his grandsons well-to-do farmers through the mere growth of the community and the rise in land values.

In fact, until about 1920, a rapid increase of land in farms in the United States was accompanied by a similar increase in the value per acre of farm land and buildings except for the period 1880–1900. (Table 9.)

TABLE 9.—*Land in farms and value per acre of farm land and buildings in the United States*

Census year	All land in farms	Value per acre of farm land and buildings	Census year	All land in farms	Value per acre of farm land and buildings	Census year	All land in farms	Value per acre of farm land and buildings
	Acres	*Dollars*		*Acres*	*Dollars*		*Acres*	*Dollars*
1850	293, 560, 614	11. 14	1890	623, 218, 619	21. 31	1925	924, 319, 352	53. 52
1860	407, 212, 538	16. 32	1900	838, 591, 774	19. 81	1930	986, 771, 016	48. 52
1870	407, 735, 041	18. 26	1910	878, 798, 325	39. 60			
1880	536, 081, 835	19. 02	1920	955, 883, 715	69. 38			

Based on Bureau of the Census reports.

Previous to 1900 agriculture was advancing, in general, on to better and better land, and prices of farm products were comparatively low. The increase in value of farm land and buildings was, consequently, comparatively low. After 1900, however, when settlement advanced to the poorer and drier soils of the West the value of land increased more rapidly than during the previous decades. The World War accounts for the very rapid increase between 1910 and 1920. Then came the precipitous decline in the value of farm real estate during the last decade, and there are many indications (March, 1932) that the bottom has not been reached.

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The settler of to-day must face problems quite different from those that confronted the pioneers who settled the prairies and the Great Plains. In these areas the land was level and clear of trees. A start could be made with a relatively small amount of capital. The prospects for large increases in the value of land were bright. Land-settlement policies which were applicable under such conditions are no longer adequate. Social controls of the direction of settlement were then lacking, but they were probably not so necessary as they now are to direct the flow of immigrants to lands best suited for farming purposes and to insure adequate educational, transport, and other public services deemed necessary to maintain minimum American standards of living.

FEDERAL LAND-SETTLEMENT ACTIVITIES

THE PUBLIC DOMAIN

It is estimated that the public domain, or all lands which were owned by and were subject to sale or other methods of transfer to private ownership at any time by the Federal Government, totaled 1,442,220,320 acres. Only 12.4 per cent of this area remains to be disposed of.

Practically all of the remaining public domain is in 11 Western States. Only a small part is suitable for cropping or for growing timber; some of it is absolute desert; and the highest use for most of the remaining area, if it can be used at all, is for grazing under conditions that require a very large acreage per head of cattle or sheep. Since 1922 there has been a gradual decrease from the 10,000,000 to 14,000,000 acres patented annually during the previous decade to less than 2,000,000 (1,938,864) acres patented during the fiscal year ended June 30, 1931. Although unfavorable prices for farm products may have had some effect, the fact that little of the remaining public domain is worth homesteading under the terms of existing acts is the direct cause of the decrease.

The legislation which played an important part in the disposition of the public domain has outworn its usefulness. With the exception of calling attention to the preemption acts repealed by Congress in 1891 only the more important kinds of legislation which are still in force are reviewed in this bulletin.

PREEMPTION ACTS

The preemption act passed in September, 1841, and repealed 50 years later, is considered one of the most important of all land laws enacted in the United States up to that time. It established the right of settlers to settle on and improve unappropriated public lands and later buy them at a minimum prevailing price. The act gave the actual settler the privilege or preferential right to buy a tract of land without competition from speculative and other nonresident potential purchasers. In short, the act as finally amended eliminated competition in the case of the purchase of public land by any person 21 years of age or older if he resided on it, had partly improved it, and did not own 320 acres. The law permitted him to buy at $1.25 or $2.50 per acre, a maximum of 160 acres of such public land.

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HOMESTEAD LAWS

The original homestead law has been amended several times, and each amendment has granted more liberal terms to actual settlers. In substance the present law grants, without charge except for registration fees, to every applicant who is the head of a family or above 21 years of age, 160 acres (or more, under certain circumstances and special acts) of public land open for entry on condition of actual settlement on and improvement of the land. The title to the land passes to the homesteader after three years of residence on the land and compliance with other minor stipulations. Under this law more than 1,333,000 homesteads, representing more than 200,000,000 acres, have been patented.

Possibly the greatest weakness of the original homestead act was the fact that it limited the size of a homestead to 160 acres. In actual practice twice that acreage in the western half of the United States is not enough, whereas in some parts of the eastern half of the country, 80 acres are enough, to establish a profitable family-sized farm enterprise. Commonly, the acreage of semiarid land that could be homesteaded was too small to support a family comfortably if used for grazing and too large if used for irrigated farming. To remedy this situation west of the one hundredth meridian, Congress in 1909 passed the enlarged homestead act which made it possible to obtain 320 acres of nonirrigable land as a homestead in certain States.[7] The fact that only slightly more than 2,500,000 acres out of a potential 193,000,000 acres of land classed as suitable under this act were actually homesteaded proves that the act is not solving the western homesteaders' difficulties. In 1916 Congress passed the stock-raising homestead act which provided that 640 acres of land suitable only for grazing or forage shall be the maximum homestead. A large proportion of the grazing homesteads, however, were also too small to maintain enough stock for a reasonable standard of living. Many grazing homesteads were patented and later sold to stockmen who owned or were acquiring large ranches.

As lands in the remaining public domain are for the most part nonagricultural in character, the homestead laws have outlived their economic usefulness. It is unlikely that in the future any large area will be taken up under existing homestead provisions, but a few persons probably will continue to enter land under the misapprehension that it will provide an adequate livelihood for a family. Lands will also be homesteaded with the object of selling out to ranchmen who own adjoining lands.

DESERT LAND ACT

The desert land act, approved March 3, 1877, was designed to promote the reclamation of lands (exclusive of timber lands) which will not produce some agricultural crop without irrigation. Under this act, title to 640 acres of desert land could be obtained at the rate of $1.25 per acre. Six hundred and forty acres was

[7] With amendments to the act of 1909 the entry of 320-acre homesteads was authorized in the following States: Arizona, California, Colorado, Kansas, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. (Gen. Land Off. Circ. 541 (*35, p. 39*).)

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granted on the assumption that land the entryman could not use could be sold to help him bear the cost of reclaiming 80 acres. In 1890, Congress limited the area obtainable by one entryman to 320 acres and stipulated that a minimum of $3 per acre or an average of $1 per year for three years must be used for reclaiming the land. Patent to homesteads is not issued until proof of reclamation is made.

The weaknesses of the desert land act are many. It failed to provide for a plan of irrigation and was applicable only to tracts that could be irrigated economically by an individual irrigation system. As a consequence much land passed into private ownership because of inadequate irrigation schemes. Inability of the majority of entrymen to supply their own irrigation systems and difficulty of establishing an irrigation district and getting a private engineering company to undertake the task of constructing irrigation works until the entrymen had title to the land, which in turn could not be obtained before the land had been improved, resulted in failure of the act to fulfill the promises of its advocates.

Figures on the actual acreage of desert-act lands that were improved are not available. Of the 32,756,082.37 acres entered under this act until June 30, 1931, slightly more than a fourth (8,635,284.56 acres) has been patented (*32, p. 42*).

The weaknesses of this act stimulated the movement for State ownership of desert lands. It was argued that large landed estates would be built up under the act without improving the land and that irrigation operations required close supervision which the States could extend better than could the Federal Government.

CAREY ACT

The Carey Act (act of August 18, 1894) was passed by Congress to overcome the weakness of the desert land act and to meet the growing demand for turning the desert land over to the various States in which it was located. Under this act the Government agreed to donate 1,000,000 acres to each State having arid land (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming) on condition that the State provide for its reclamation. Additional grants were made to Idaho and to Wyoming, the only States that applied for more than 1,000,000 acres.

This act authorized the States contracting for the land to exercise full regulatory powers over the reclamation and settlement of the land. Under the contract between the States and the United States Department of the Interior, the State assumes the responsibility for the reclamation and sale in small tracts not exceeding 160 acres to any one individual of the lands segregated under the act, and binds itself to cause to be irrigated, reclaimed, and occupied, not less than 20 acres of each 160-acre tract cultivated by actual settlers within 10 years after the date of the approval of the State's application for the land. In the operation of the Carey Act the work of reclamation is undertaken by private enterprise under contract with the State.

Before the State enters into contract with a private construction agency, it must pass upon the feasibility of reclaiming land under the plan proposed by the construction company, the sufficiency of

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water rights, the capacity of the proposed works to irrigate all lands selected, the reasonableness of the cost of construction, and the financial ability of the company to construct the project. The contract with the construction agency contains complete plans and specifications for all proposed works and the maximum price and terms per acre at which water rights shall be sold to settlers, the maximum maintenance cost, annual tax, and the price and terms upon which the land is sold to the settlers by the State.

Citizens who wish to take up Carey Act land must contract to settle upon and improve the land. Three years after receiving adequate water on the land, each settler makes final proof of reclamation, settlement, and occupation of his tract of land; makes final payment to the State; and receives a patent or deed from the Federal Government through the State for his land.

The law provides that a lien for the reimbursement of construction charges is held by the contractor against every separate legal subdivision of land reclaimed. This lien is for the actual cost and necessary expenses of reclamation, and must be paid by the settler in addition to the price paid to the State for the land.

The Twin Falls area in Idaho is an example of the successful development of a Carey Act project. In a little less than the 20 years during which the project was developed, the assessed valuation of the area in the project had increased from the value of a sagebrush wilderness to $29,164,979. All the irrigated land had been settled, and the old private company that built the works had been completely paid off.

But the majority of Carey Act land projects have not fared so well. Up to June 30, 1931, out of a total of 8,465,601 acres applied for, 4,399,881 acres, or 52 per cent, had been rejected before segregation; 2,062,110 acres, or 24.4 per cent, had been canceled after segregation; and only 1,174,903 acres, or 13.9 per cent, had been patented (*32, p. 52*). These figures do not bear out the hopes of the sponsors of the Carey Act. The promotion of many of these projects was financed by funds advanced by settlers and not by the promoters; ill-advised projects were a natural consequence.

In January, 1921, Congress passed an amendment to the Carey Act designed to curtail hurried and ill-advised projects. By this amendment the Secretary of the Interior is authorized to restore segregated land to the public domain unless actual construction work is begun within three years or if the land is not actually irrigated within 10 years. The evident weakness of this act hurried the passage of the act providing for Federal construction of irrigation works.

FEDERAL RECLAMATION ACT

A series of Federal legislative acts aimed to remove the obstacles to the establishment of small owner-operated farms on western lands that need irrigation. Beginning with attempts to remove the obstacles to reclamation by private enterprise, these culminated in the passage of the reclamation act on June 17, 1902. The act provided for Federal construction of irrigation works, with advances of Federal funds for long periods without interest—a partial subsidy.

Up to the present time national land-reclamation policy has been confined entirely to providing water for arid lands. Although there

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have been many proposals within the last decade to extend the system of Federal reclamation to include the drainage of swamp lands and the scope of the policy to cover the United States, no such legislation has been enacted, aside from flood-control measures administered by the War Department which frequently involve the reclamation of land. The diking of Lake Okeechobee in Florida, and making navigation possible from this lake to the Atlantic and the Gulf, is a project of this latter class. A levee was constructed around Lake Okeechobee to provide protection against overflow from storm tides in the lake. This levee does not result in draining swamp lands around the lake.

The Federal reclamation act provides that repayments of construction costs are to constitute a revolving fund to promote further reclamation of lands. But, throughout the 25 years and more since the establishment of the policy, the fund has failed to revolve as fully as was originally planned, necessitating a series of acts, lengthening the period of repayment or embodying special relief measures.

Up to June 30, 1931, $206,041,522.20 of interest-free Federal money was represented in works constructed, and the Bureau of Reclamation was ready to supply water to a total of 3,634,112 acres.[8]

The use of interest-free Federal funds to construct irrigation works brings land into cultivation that could not be reclaimed profitably without such a subsidy. In fact, when interest is not charged on advances for construction, a farmer can assume a larger indebtedness than if interest payments must be made. When such charges have to be met the net income from farming decreases accordingly and the farm must be recapitalized on a lower level of value.

Briefly, the ultimate effect of the subsidy is to stimulate the reclamation of lands from which probable earnings would not justify the large capital outlay after interest must again be taken into account. Furthermore, interest-free funds strengthen the motives for exerting political pressure for reclamation projects and make it difficult to avoid ill-advised undertakings (*37*).[9]

STATE LAND-SETTLEMENT ACTIVITIES

The special interests of the States in policies that promote the establishment of prosperous farming communities are justified on the basis that such communities mean increased business for local private enterprises and increased tax money for public service. Unoccupied and unused land has little capital value. If the land is converted into improved farms, forestry projects, recreation centers, or other uses to which it may be adapted, the taxable value immediately becomes apparent. Too frequently, however, communities let their zeal to obtain new settlers obscure the consequence of permitting a sparse and scattering type of settlement.

The costs per unit of area for adequate schools, roads, and other public services in such areas are not much less than in a well-developed area. The tax load on farm property and on lands that yield no income, has a tendency to promote the reversion of land to public ownership through nonpayment of taxes, and to pyramid the tax load

[8] Includes Warren Act lands (*27, pp. 60, 90*).

[9] For a more detailed discussion of past and present land reclamation policies of the United States, see Department Bulletin 1257 (*36*).

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on remaining tax-paying land, leading to farm abandonment and additional tax delinquency (*17*, *18*). This is evident in many sparsely settled areas to-day. Attempts to farm land that is physically unsuited for agriculture lead to similar evils.

Disillusioned settlers, decay of community enterprise, and other social and economic losses, have always followed unwise expansion of the agricultural area. This fact has not been recognized in the many State laws concerning the settlement of land. Until recent years the States, with few exceptions, left the settler to the private land-selling agencies, or seconded the efforts of these agencies in attracting settlers. The evil results of a laissez faire policy of land settlement and the changed outlook for obtaining settlers induced many States to adopt special policies for attracting settlers, during or since the World War, both supplying credit to settlers and establishing colonies of settlers.

Information concerning State policies and other activities which in one way or another influenced land settlement, was obtained for the purposes of this bulletin, by interviews with officials in the majority of States, and by correspondence with officials in the remainder. These materials have been supplemented by the use of State reports and other publications concerning the different phases of land-settlement policy in the States.

Results of this study showed that, although the consequences of haphazard settlement are fairly well recognized, the State legislatures in general have not enacted substantial legislation to cope with existing problems. Several of the States have undertaken highly desirable work along certain lines, but no State has formulated an adequate land-settlement policy.

In no State does a single office administer the variour laws that concern land settlement. As a consequence, continuity in policy is handicapped. The land-settlement policy of no State is in direct conformity with the letter of laws pertaining thereto. Many laws and features of particular laws have never been enforced; or they have not been enforced during the last several years. Funds have not been available, there have been changes in executive policy, or there have been other reasons. In Minnesota, for example, although the statute creating a State board of immigration and outlining its duties has not been repealed, the work of the board was discontinued through failure of the 1927 legislature to appropriate any funds for the board. In other States appropriations for specific types of work authorized by law have been reduced or new uses have been found for funds formerly employed for a particular purpose under authorization granted by a land-settlement law which has outlived its usefulness but has not been repealed.

Thus in describing the administrative policy of offices concerned with one or more phases of land settlement, a description of all State laws designed to promote, direct, and/or regulate one or more phases of land settlement is likely to be misleading. No attempt has been made in this bulletin, therefore, to describe all existing State laws on the subject. The purpose has been to review the experience of various offices in administering particular laws and types of legislation expressed in important prevailing policies of the different States.

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The land-settlement policies appear to group themselves as follows: (1) Policies to get the settler on the land, (2) policies to finance the settler, and (3) land-settlement regulatory policies. Many of these policies failed to accomplish the ends sought. Underlying the many reasons that might be given for the failure of such policies is the lack of coordinated effort on the part of various State and Federal offices dealing with different phases of land settlement. The various classes of legislation concerning one or more phases of land settlement are administered independently of one another rather than as integral parts of one program. Overlapping and contradictory practices are a natural consequence.

Although a particular policy may have been destined to failure from the beginning because of inherent weaknesses, the fact should not be overlooked that it was after, and not before, most of the policies referred to were put in force that the factors have developed which recently so profoundly influenced agricultural supply and demand. The Federal immigration laws have been made more stringent; birth rates have showed a decided tendency to decline; horses have been replaced by tractors to a great extent and other far-reaching changes in production technic have become more or less generally practiced; foreign demand for crops produced at a price which would bring a profit to American farmers has decreased; and marked changes have also taken place in the consumption habits of people in the United States.

These and related factors which undoubtedly operated to promote the failure of certain State policies here considered had not been foreseen. A certain degree of failure was inevitable when such factors were combined with the obstacles that arise when a political entity like the State, or the Federal, Government attempts to promote agricultural expansion through subsidies or other artificial means. Private industry always has and probably always will provide for the needful expansion of the agricultural area. Our past experience suggests that the function of the Government in such an expansion program is, in general, to provide the necessary factual information and the regulatory measures needed to direct settlement to those areas capable of being developed most economically.

POLICIES TO GET THE SETTLER ON THE LAND

Among the first regularly organized efforts of the States to induce settlement was that by which each State advertised its attractions and opportunities. Private and public institutions used practically the same forms of advertising. Inducements used to interest people in going into a new country and taking up or buying land included extravagant posters and printed material scattered broadcast through the mails; exhibition trains decked with banners and loaded with fruits, vegetables, and grains impossible to duplicate under ordinary farming conditions; homeseekers' excursions; elaborate exhibitions and professional lectures; and virtual promises of quick and easy riches.

The futility of such practices from a public point of view has been demonstrated. Although much remains to be corrected, many of the States are now making effective efforts to confine their adver-

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tising to a conservative statement of facts. The policy of many States, particularly the New England States, to emphasize the use of abandoned farms for summer homes and other recreational purposes rather than as potential profitable farming enterprises is a movement in the right direction.

Up to 1930 State agencies in 24 States [10] were authorized by law to collect, compile, and disseminate to would-be settlers and others, available information concerning the climate, soil, resources of the State, and any other factors which might have a tendency to attract population and capital to the State.

The publications may be maps, circulars, folders, bulletins, etc. Special articles concerning the State's resources are prepared for publication by officials in practically all States. In most of these States such special articles are released at irregular periods, but in South Dakota the secretary of agriculture prepares a weekly article that is given wide distribution. Ten States (Georgia, Kentucky, Louisiana, Maine, Massachusetts, New Hampshire, Tennessee, Vermont, Virginia, and West Virginia) publish descriptions of farms for sale or rent.

In Louisiana any citizen may register land held for sale in the office of the commissioner of agriculture and immigration. An abstract of title and a brief description of the property must accompany the request to register land. Letters requesting names and addresses of agencies having lands for sale are mailed to chambers of commerce and to local newspapers. Information obtained from agencies and others who have land for sale is condensed and published in an annual list of Louisiana lands for sale bulletin. Prospective purchasers who inquire of the department are referred to the owners of land listed in the bulletin. The West Virginia Department of Agriculture publishes semimonthly a list of farms for sale; about 50,000 copies of this list are distributed monthly. Approximately 10,000 copies of a similar list are distributed monthly in New Hampshire.

Many States still maintain the policy of advertising extensively by means of exhibits of agricultural products. Some maintain permanent exhibits in the State capitols or other public buildings; others send annual exhibits to State and county fairs.

With a few exceptions, the expenditure for advertising the resources of the State has been eliminated or appreciably curtailed during the last few years. The decrease of activity is due less to an appreciation of the lack of an economic need for more farm land than to the feeling that prospective settlers are few in number and the cost of extensive advertising is too great for the results obtainable. Officials in general stated to the writer that as soon as "agriculture picks up" extensive advertising campaigns would again be the practice.

The States in which extensive advertising campaigns have not been curtailed, or have been made more intensive, seem to have shifted their emphasis from attracting prospective farmers to attracting tourists. For example, in 1927, the Minnesota Legislature abolished the State board of immigration by failing to appropriate funds; the bureau had been spending about $3,000 a year in

[10] See Appendix for names of State agencies.

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classified advertisements to get in touch with prospective farmers. To-day the legislature supports the work of the Ten Thousand Lakes—Greater Minnesota Association with an annual appropriation of $37,500. The purpose of this association is to advertise the recreational and agricultural resources of the State. Its main support comes from real-estate agencies and resort owners. The names of prospective settlers or purchasers of resort property are mailed to each real-estate dealer who pays a $10 annual due to the association.

Similarly, in 1929, the Michigan Legislature authorized an appropriation of $200,000 for the biennial period ended July 30, 1930, for advertising the resort and farming advantages of the State by matching dollar for dollar up to $25,000 annually with each of four private and semipublic promotional organizations.

HELPING THE SETTLER GET LOCATED

Virtually every State is engaged in advertising its resources for the purpose of attracting settlers and capital, but at this point, with few exceptions, the State withdraws and turns the prospective purchaser or investor over to the private land-selling agency. That this policy should be adopted by the majority of States is not surprising when it is remembered that an unbiased set of basic facts necessary to evaluate farming possibilities has not been made available in any State. The land-inventory work in Michigan, Wisconsin, and Minnesota, is supplying needed facts, but even in these States a well-rounded policy is lacking to direct the prospective purchaser of land to good farm property. (See pp. 71 to 76.)

Several States make a more or less cursory attempt to check up on the reliability of real estate agencies before names of prospective purchasers are turned over to them. In most States, however, the names and addresses of inquirers are given directly to real-estate agencies and State officials tell the prospective settler to look over any land carefully before buying. Without adequate facts on rational land utilization in this or that section of the State, the settler lacks guidance.

Michigan makes a positive attempt to get the prospective settler in touch with reliable land-selling agencies and at the same time makes available to him an unbiased analysis of the possibilities of establishing profitable farming on the types of land held for sale by the land companies. This work grew out of a land certification act passed by the Michigan Legislature in 1923. The act provides that any dealer in land, upon request to the State department of agriculture, may have his land surveyed, inventoried, charted, and certified as to the use for which it is found to be best suited. All work is to be under direction of the State department of agriculture at the expense of the applicant. The act provides that a copy of State certification is to be attached to each deed for conveyance of land. Only 15,885 acres of land have been certified under this act, and no land has been certified since December, 1925.

The ineffectiveness of this law, so far as directing land settlement is concerned, is suggested by the fact that most of this small acreage was ordered certified by trustees of estates and not by land-selling agencies. This act represents a constructive attempt to protect

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both the unwary settler and the legitimate land-selling agency from those agencies which prey on the public and the uninformed prospective settler. Before much good can result from a law of this kind, however, its use must be obligatory and not optional on the part of sellers of land. Furthermore, since it is to the interest of the State and to the Nation to prevent unwise settlement of land and the social and economic loss that follows, it would appear to be the proper function of Government, State and National, through duly constituted public agencies to obtain, at public expense, the basic facts necessary for land certification.

Policies to Develop and Sell Ready-Made Farms

Policies to establish colonies of settlers according to fixed plans have been provided for by the legislature of 13 States,[11] but establishment of such policies has been undertaken in only six States. The general purpose of the legislation in each of the remaining seven States was similar, in that purchasing, improving, and selling land for agricultural use was the essential object; preference in purchasing land was to be given to soldiers, sailors, and marines; and the materialization of the plans proposed in the legislation was dependent upon cooperation with the Federal Government in financing the project. Since Congress failed to provide for such cooperation the legislation in the seven States failed to become effective.

Although the experiments to establish colonies by the six States which had such policies (California, Washington, South Dakota, Arizona, Minnesota, and Oregon), differed in detail—the general objective in each was to develop and sell "ready-made farms." The experiments are also similar in so far as results are concerned—each failed to accomplish the ends contemplated.

The experiments of the different States in developing and selling ready-made farms were initiated during a period of comparatively high prices for farm crops, probably on the assumption that the level of prevailing prices for farm crops would increase or at least remain at existing levels indefinitely. This assumption is an underlying factor considered in each of the six States along with three other closely related factors: To help ex-service men and others get established on farms under favorable conditions; to obtain competitive advantages in bidding for a decreasing number of potential settlers; and to increase the assets of the State by stimulating the development of large areas of undeveloped land.

A period of falling prices for farm crops and general agricultural distress began shortly after these experiments had been started. Whether one or more of the experiments would have succeeded under more favorable agricultural conditions is an open question. There is no record of the success of any similar project, State or private, in the United States which was begun during or since the World War. In the following discussion, therefore, no attempt has been made to analyze the various factors and conditions that contributed to the success or failure of the projects but rather to briefly describe the results of each experiment.

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[11] California, 1917; Minnesota, 1917; Utah, 1917; Colorado, 1919; Idaho, 1919; Oregon, 1919; South Dakota, 1919; Washington, 1919; Wisconsin, 1919; Arizona, 1921; Montana, 1921; Michigan, 1923; and South Carolina, 1923.

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THE DURHAM AND DELHI PROJECTS IN CALIFORNIA

The California State settlements at Durham and Delhi are probably the best known and most discussed of the State experiments to develop and sell ready-made farms. The first was established at Durham, Butte County, in 1918, and consisted of 6,239 acres of generally good land under a gravity system of irrigation from Butte Creek. A detailed soil survey was made by the University of California and on this basis the tract was divided into farm units varying in size according to the productivity of the land and the needs for the type of farming which seemed best adapted. These comprised 110 farms from 8 to 300 acres in size and 30 farm-laborer allotments from 1 to 2 acres in size. Provision for laborer tracts was among the innovations in this colony.

After all disputes and controversies over water rights in Butte Creek were settled, the land was prepared for occupancy by building a system of irrigation ditches reaching each settler's farm; providing for drainage and protection from flood; organizing a mosquito district; preparing plans for houses; arranging for obtaining wholesale prices on building materials; and planting most of the land to crops.

The large number of applicants for the available holdings made it possible to select settlers with great care. Any citizen of the United States or any one who had declared an intention to become a citizen, who did not already possess agricultural land which, added to his State allotment, would amount to $15,000 or more in value, and who was ready to begin actual residence on the land within six months, might become the purchaser of an allotment provided he could meet other requirements. Due consideration was given to the applicant's net worth, his temperament, physical and mental ability, his experience, and the character of his family. When the colony was first established each accepted candidate was required to have at least $1,500 or its equivalent in suitable equipment. Later the requirement was raised to $2,500.

Each approved applicant entered into a contract to pay in cash 5 per cent of the sale price of his allotment, and not less than 10 per cent of the cost of the improvements that the State had made thereon. The balance due on the land was to be paid in amortizing payments over a period of about 40 years, with interest at 5 per cent per annum. The improvements were to be paid for in amortizing payments covering 20 years, and all loans made on personal security were due in 5 years.

The original appropriation for developing this colony proved inadequate and in order to have available funds a number of settlers were required to borrow one-half the capital value of their farms from the Federal land bank and apply the money obtained as advance payments on their contracts. The settlers who obtained Federal land bank loans had to pay 5½ per cent rather than 5 per cent interest, but they were thereby enabled to pay off their 20-year and 5-year loans and then have smaller payments to make over a longer period.

The purchaser contracted with the State to cultivate the land and keep up repairs on the improvements under the supervision of the board, to keep up all insurance, and to live on his allotment at least

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eight months of every year. No allotment might be sold or exchanged without the consent of the State until paid for in full.

Should a settler fail to live up to his contract, the State had authority to cancel the contract and regard all payments made prior to the cancellation as rental for the property. Those in charge took many precautions to guard against failure of the individual as well as of the settlement as a whole. The settlers were helped to make their regular payments to the board by opportunities to add to their farming incomes by working for each other, and by taking part-time or seasonal jobs at neighboring ranches.

Under the terms of the act and by the administrative policy of the officials in charge of the undertaking, settlers began under circumstances that tended to eliminate the usual hazards of beginning new farm enterprises. The officials were authorized to spend $1,500 on each farm for livestock and farm equipment. The purchaser came to a ready-made farm that had usable buildings. His own capital of not less than $1,500 minus the cash payment, could be used as operating capital. By these arrangements the settlers were not subjected to the pioneering stage with its hardships, its self denial, the discouraging struggle to subdue the land, and the retarded development owing to lack of equipment and working capital.

The initial period of development of the Durham project appeared to be so successful that all available allotments were readily sold. Farmers and prospective farmers in large numbers were anxious to avail themselves of the paternalistic policy of the State. All went well until prices of farm products dropped and the settlers were dependent upon their own resources to meet their obligations. When this occurred a number of settlers served notice of rescission of contract of purchase. Those filing rescission notices made three allegations as follows (*8, p. 756*):

1. That the consent of the rescinding party was given by mistake.
2. That the consent of the rescinding party was obtained through fraud, exercised by or with the connivance of the state.
3. That through the fault of the state, the consideration for the obligation of the purchaser in said contract contained, has failed in part.

Whether these accusations are valid is not an essential factor in this discussion. In the light of the present status of the project they serve as additional illustrations of the weaknesses of this type of land-settlement policy.

On November 30, 1928, 866 acres or 14 per cent of the lands were held for sale by the State; 296 acres or 5 per cent had been resold for cash; and 5,077 acres or 81 per cent were held by settlers on contract. The settlers owed the State $538,637.47 of which amount about one-fifth or $112,780.54 was delinquent. In addition to this indebtedness the settlers owed $62,068.44 to the Federal land bank.

From the point of view of financial loss to the State, the Durham settlement is much less of a failure than is the Delhi settlement. Unfortunate conditions at Delhi appear to have been due largely to the selection of land, which proved to be less favorable for economical development, and to the fact that the project was undertaken just before the close of the period of high costs and prices that prevailed during and following the World War.

The Delhi tract, consisting of 8,400 acres, required a very expensive system of irrigation. It was necessary to construct an under-

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ground pipe system to carry the water to each allotment. The character of the soil made carrying water in small unlined ditches extremely impracticable. The system cost over a million dollars and required three years in building. A large expenditure of State funds and a heavy interest burden before land is ready for settlement make difficult loads at any time for settlers whose money must come from crops produced on poor soils. This is especially true during a period of low prices for farm crops.

An extensive road system was laid out and improved; a detailed soil survey was made, and the tract was subdivided and held for sale on practically the same plan followed with the Durham project. But settlers were not so eager to buy land in this project as they had been in the Durham project. In fact, at no time was all the land in the project sold, and many farm units that had been sold reverted to the State and were offered for resale.

In July, 1923, the Delhi Settlement reached a state of desperation. Income from the farms would not supply the necessities of life and besides there were taxes, water charges, and interest on Federal bank loans. Resources of the settlers were exhausted. No installment payments had been made on 95 per cent of the purchase agreements and they had been forfeitable for more than three years. The Settlement being remote from industrial activities, no outside work was obtainable, and, with buildings, had cost the settlers $400 an acre. Necessary improvement in the way of fruit, vines, dairy, and poultry equipment has increased and will continue to increase the price beyond the probability of adequate return. Such consideration, coupled with the past three years of pioneering work devoted to the conversion of the undulating sand plain into plantations of alfalfa, fruit and vine farms, had exhausted both the physical and financial resources of the settlers (*8, p. 751*).

In 1925 a special legislative committee made an investigation and reported in part as follows:

The final consideration of this problem has led your committee to recommend that the State of California should never enter into another land settlement scheme (*5, p. 5*).

Beginning in 1927 when a division of land settlement in the State department of agriculture was placed in charge of both State land settlements, steps were taken to retire the State as a land-colonization agent. The difficulties in accomplishing this end were not easily overcome.

On December 1, 1928, 3,890 acres or 46.3 per cent of all land in the Delhi project remained unsold and a revaluation of all property in the colony shrank the State's equity from $1,307,000 to $375,000 and the settlers' equity from $500,000 to $375,000.

Very many of the settlers were ready to fly at the throat of California with charges of fraud and misrepresentation in the promotion of the colonies. Most of them owed much more on their land contracts, improvement contracts, and notes than the value of their property amounted to, and it was impossible for them to meet their obligations * * *. Every act on the part of the State was looked upon with suspicion by settlers who regarded it as an attempt to defraud them * * * (*9, p. 322*).

A plan was finally formulated to adjust the $375,000 settlers' obligations to the individual properties, and thereby close the account of a costly experiment to the State. Under an act of the legislature in the spring of 1931 the State, following a complete readjustment of State land-settlement affairs, withdrew completely from land-settlement activity in both the Durham and Delhi projects. On

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August 14, 1931, all farmer and laborer allotments which reverted to the State and all other unsold land and other property in both projects were transferred to the control of the department of finance, division of State lands and the division of land settlement and the State land settlement board, which had been charged with the duty of administering this State experiment in establishing colonies, were abolished.

By this transfer the State of California wrote off $2,500,000 as the cost of its paternalistic venture in colonization at Delhi and Durham. Under present conditions every element of paternalism has been removed and the position of the State as the holder of notes secured by deeds of trust and as the owner of unsold land is similar to that of a bank.

THE WHITE BLUFFS-HANFORD PROJECT IN WASHINGTON

The White Bluffs-Hanford settlement in the State of Washington represents another unsuccessful State experiment to establish settlers on the land. This project differs from the California project in several ways. Chief among these differences are: (1) That the settlement, which consisted of 102 farm units of about 20 acres each, was scattered over a distance of 14 miles, and (2) that each tract required an individual pump irrigation system. The wells averaged 36 feet deep. They were supplied with a concrete curb and an irrigation pump which had an electric motor to lift the water to the surface. Power could be purchased from a local company.

The land was all examined and approved by the department of soils of Washington State College from the standpoint of its agricultural possibilities. Only those tracts found suitable for farming were recommended to be included in the settlement project.

Since the tracts included in the project were scattered or infiltrated among the ranches and apple orchards already established in the valley, the State did not find it necessary to use State funds for constructing community houses, roads, light systems, etc. This helped to keep down the price of the land to the settler. The project also differed from the California projects in that the Washington authorities did not undertake to improve farm units until settlers had contracted to purchase them, and then improvements would be made only to the extent requested by the settler. The aim was to keep funds from being tied up in improvements on unsold tracts. After a settler had agreed to buy a tract, the State, on request of the settler, would place the following improvements on the land at the prices indicated:

A 3-room plastered and painted cottage on a concrete foundation with a 9 by 9 foot concrete walled cellar, wired with electric lights, and a small modern poultry house	$1,500
An irrigation distribution system	1,625
Clearing, leveling, and seeding 5 acres	200
Fencing material for outside areas	200
Power furnished for three years	525
Total State expenditure for improvements	4,050

In the assignment of allotments soldiers were given preferential rights, and provision was made to select applicants with care. A qualified applicant was required to be a citizen, to be worth less than

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$15,000, and to satisfy the board as to his financial and physical fitness, to cultivate and develop a farm.

As in the California colonies, an attempt was made to adjust the terms of the contract to the conditions of the settlement and at the same time to safeguard the State against loss of funds. Each approved applicant contracted: To occupy the land within 6 months after purchase and actually reside on it at least 8 months in each year for a period of 5 years; not to assign the land without the consent of the board; to pay for the land in annual installments, with interest at 4 per cent within a period of 20 years; to pay in cash 40 per cent of the cost of his pump and motor, 10 per cent of the cost of the land, and 10 per cent of the cost of all the improvements advanced by the State.

Prompted by the stress of the agricultural depression and the difficulties of getting the tracts in use a special ruling provided that deferred payments on the land might be made as follows: One dollar plus interest at 4 per cent on all deferred payments on January 1 of each of the first 3 years, and the remainder of the indebtedness to be amortized at 4 per cent in 20 years.

The raw land was sold to the settlers for $30 per acre, or $600 for the tract. When the unit was ready for occupancy, if the State had made all improvements, it represented an investment of $4,650. On this the settler was required to make a cash payment of $612.50; $240 on his pump and motor; $60 on the land; and $312.50 on the improvement. He retained the remainder of his cash for stock, implements, and operating costs.

Although 58 of the 102 units of 20 acres each had been prepared for settlement as early as 1923, up to May, 1925, only 69 tracts had been sold on contract; the remaining tracts were unoccupied, and steps were being taken to discontinue State activity on the project. At that time the State had invested $448,497.43 or $4,789.19 per tract. The investment in unsold tracts was $132,437.95 or $3,895.23 per tract.

Among the more basic weaknesses of the project, found by the State department of efficiency (*10, p. 1–88*), the following may be mentioned: The soil, when cleared, powdered and blew freely unless planted to cover crops; one settler planted alfalfa seed eight times on one field and failed to secure a catch; there was insufficient water to irrigate the land, and the cost for power to pump the water was prohibitive; profitable farming was found to be next to impossible, and the State was accused of misrepresenting facts to prospective settlers. These weaknesses and accusations led to the passage of a law creating a land-settlement adjustment board with powers to make such adjustments in the contracts between State and settlers or such settlements with contract holders as it deemed advisable. It was also empowered to dispose of the remainder of all property included in the project.

Synopsis of board's report (22, p. 69)

Negotiations between the board and the settlers resulted in the State giving quitclaim deeds to all settlers but six. Sixty-one tracts at a total investment of $347,724.69, an average per tract of $5,700.40, not taking into consideration the cost of administration, were deeded to the settlers for a consideration

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of $1.00 each. In addition, three settlers accepted cash in lieu of deeds, these amounts being $800.00, $1,250.00 and $650.00. Two settlers rejected the board's proposals and are still holding their tracts under the original contract.

Unoccupied Tracts

The board then made an appraisal of the thirty-nine unoccupied tracts, and placed a valuation of $34,925.00 thereon.

The unoccupied tracts were offered for sale by publication of a notice in the Hanford Herald for five weekly issues prior to the date of sale, and by posting the notice of sale for the same period in the office of the County Auditor of Benton County. The sale was held at Prosser, Washington, by the County Auditor of Benton County, at the Court House, at ten A. M., June 1, 1926, the State realizing $48,210.00 from the sale of the tracts, or $13,285.00 more than the appraised value.

The terms of sale were one-tenth down, the balance in nine equal annual payments, with interest at six per cent per annum on deferred payments, the contract due date being June 1st of each year.

The board concluded in substance that it was economically and socially unsound for the State to develop ready-made farms for sale to settlers.

Up to June, 1930, several tracts, sold in 1925, had reverted to the State, and many payments on the unoccupied tract, sold at the same time, were delinquent.

THE LAND-SETTLEMENT EXPERIMENT IN SOUTH DAKOTA

The South Dakota land settlement act created and authorized a land settlement board to purchase, improve, and sell land; to set aside areas for town sites and to plat such sites and sell lots; to set aside land necessary for public use such as schools, roads, etc.; to improve or furnish money for improvement and equipment on land sold to settlers, on land which is security for a loan obtained from the South Dakota Rural Credit Board[12] or under the Federal farm loan act, or on public land sold subject to deferred payments.

The land settlement board was authorized, prior to disposing of land or before the end of the fifth year after selling land to qualified settlers, to seed, plant, and fence land and to construct needed buildings and make other improvements. In substance the act authorized establishing group settlements along lines similar to those followed in the Durham and Delhi settlements in California, in addition to making liberal loans to settlers who wished to buy or who had bought farm units they themselves selected. Although 10 quarter sections of land in Todd County were bought for the purpose of developing a group settlement similar to the Durham project, the colony was not developed. Instead the land was held for sale on the same terms on which purchasers of other land could borrow from the board.

The primary business of the board, therefore, was loaning money for the purpose of buying land, improvements, and livestock, and paying off encumbrances already incurred. The State rural credit board took first action on applications, loaning in most cases the limit allowed by law (70 per cent of the "true value") which was construed to mean "the fairest, most unbiased valuation" the land settlement board could have placed thereon. The rural credit board took first mortgage on the land as security. The land settlement

[12] The work of the South Dakota Rural Credit Board is described on pp. 57 and 58.

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board then made additional loans up to 90 per cent of the "true value" of the property and took a second mortgage as security. Loans were made on the amortization plan payable in 30 years with interest at 6 per cent on deferred payments. The loan made by the rural credit board could be paid on any interest-paying date after the fifth year, and the loan from the land settlement board could be paid on any interest date. A measure of control of the resale of property by settlers was made possible by making mortgages held by the land settlement board immediately due and payable upon transfer without consent of the board.

The experiences of South Dakota in the field of land settlement were similar to those of California and Washington. The statute creating the South Dakota Land Settlement Board and authorizing activities of the board was abolished by the 1925 State legislature and the work that had been started by the board was turned over to the State rural credit board (March 20, 1927) for salvage purposes. Before going out of existence the land settlement board foreclosed on second-mortgage delinquencies, and the rural credit board obtained many farms for the amount of the first mortgage which it held. Out of a total of 347 farms improved by the land settlement board only 36.3 per cent represented live loans in April, 1930, 54.8 per cent had been foreclosed, and 2.9 per cent were under foreclosure. Two farms had been foreclosed and resold, and 20 had completed payments.

THE ARIZONA LAND-SETTLEMENT EXPERIMENT

The purposes of the Arizona land settlement act (*2, p. 106*) are

> to provide homes for soldiers, sailors, marines and others, to assist in the purchase, reclamation, and settlement of farms and workers' allotments, and * * * for making loans to settlers.

The various features of the act are, in substance, the same as those of the California act. Besides purchasing, developing, and selling ready-made farms the act authorizes community improvements with State funds. Land purchased is to be subdivided into farms not to exceed $7,500 in value and in workers' allotments not to exceed $1,000 in value when improved.

A qualified applicant for purchase of land and improvements is required to have a minimum capital of 5 per cent of the value of land and improvements and not be an owner of property elsewhere valued in excess of $10,000. Loans to make permanent improvements and for the purchase of farm implements, livestock, or other farm equipment, not to exceed $3,000 per farm and $1,000 per worker allotment, are authorized credit terms. The terms of sale are 2 per cent cash on value of land, plus 5 per cent cash on value of improvements; balance on land to be paid at rate of 2 per cent per year for the first 4 years, after which the remaining debt is to be amortized over a period of 30 years with interest at 6 per cent on deferred payments; balance on improvements is to be paid in 15 years with 6 per cent interest on deferred payments.

In the spring of 1922, 970 acres of land were purchased. This land was leveled and fenced and a well and a house were provided on each allotment of about 20 acres. A new feature was the attempt by the State to reduce overhead costs to settlers by renting them farm machines and implements.

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Although the Arizona land settlement act has not been repealed, the experiment begun in 1922 has not been completed or repeated. Up to June, 1930, 40 soldiers had been placed on State improved tracts and according to the official in charge not $1 has been collected from these 40 settlers and there is some question whether even the interest on State funds invested in the project will ever be collected. All funds appropriated for the work have been exhausted.

The Minnesota Land-settlement Project

The law authorizing the Minnesota State auditor to improve tracts of land did not direct specifically that colonies of settlers be established but rather that tracts of land be improved and sold as farm units. It was expected that these farms would indicate the possibilities of developing cut-over land and would eliminate many of the hardships usually so encountered. The legislature provided an appropriation of $100,000 to be used as a revolving fund for clearing and improving land. The State auditor was directed to conduct this experiment. He, in turn, appointed a land improvement board of three members who were made immediately responsible for the experiment.

The land improvement board selected out of the State lands 40-acre tracts that were classified as good agricultural land. The board then contracted with private companies to clear 5 acres on each tract and to break or plow from 2 to 3 acres of the cleared land. Not more than $300 could be spent for clearing and breaking any one 40-acre tract. The improved forties were to be sold at public auction to the highest bidders for the land without improvements, making the actual purchase price the sum of the amount bid per acre and $7.50 per acre for the improvements.

The purchaser was required by law to sign a written agreement to establish his residence upon the land, to cultivate and further improve it, and to maintain his residence on the land until the cost of improvements had been paid to the State in full. By the terms of purchase he had to pay in cash a sum equal to 15 per cent of the purchase price of the land plus 15 per cent of the cost of improvements. The balance of the cost of improvements was to be paid within 5 years and the cost of the land within 40 years with interest at 4 per cent on deferred payments. All payments on improvements were to be returned to the original revolving fund from which the money could be spent again for like improvements. The land improvement board began to function in 1918 and up to 1924, had improved over 600 of the 40-acre tracts selected.

Although the Minnesota Legislature had not repealed the act authorizing this experiment in settling land up to June, 1930, no land has been improved since 1923. Without counting resales by the State, less than one-third of all tracts improved have been sold and many of the sold tracts have reverted to State ownership. Many of the unsold tracts lie at some distance from town, lumber camps, or mines, or other sources of employment for prospective settlers. The best tracts have been sold and the cleared acreage on the others is reverting to brush and other vegetative cover. Some $90,000 of State moneys are tied up in these rapidly disappearing improvements

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and in June, 1930, officials in the State auditor's office expressed the opinion that the loss to the State will be approximately that sum in the end.

THE OREGON LAND-SETTLEMENT PROJECT

The Oregon experiment in settling land involved only three farms and can not be considered strictly comparable to any of the five State experiments previously described. The plan seems to have had greater success than any of the other five.

The 1919 legislature of Oregon established a land settlement commission and appropriated $50,000 to be used as a revolving fund to carry out the provisions of the act. The law authorized the commission to hire a manager or a superintendent and a secretary; to acquire by gift, purchase, or eminent domain, all property and lands needed for their work; to improve, lease, sell, or otherwise dispose of the land in their possession on such terms as it deems advisable; to contract with the United States Government for the settlement of ex-service men on the land; and to provide for supervisory and other work necessary to develop ready-made farms as demonstration farms.

The land settlement commission appointed as its superintendent the head of the farm-management department of the State College of Agriculture, and the commission, with the superintendent, adopted the following plan of settlement: Three units of land, each suitable for a different type of farming, were selected in different parts of the State where it was felt that guidance to settlers was most needed. The farm-management department of the college surveyed all the land in each farm unit and ascertained the best use for the various types of land. Dwelling houses with modern conveniences and barns, bins, hog and poultry houses, fences, etc., were then built according to plans furnished by the college. Each farm was operated by the State until the improvements and equipment were found to be complete and the farm was considered to be a going concern on a paying basis. After this stage, and not before, the farm was offered for sale.

The purchaser was not required to make any specific down payment but he was required to get a Federal farm loan to apply on the purchase price. The State took a second mortgage for the remainder due on the farm. The sale contract contained a clause requiring the purchaser to keep in touch with the college of agriculture and the land settlement commission and to conduct his farm operations somewhat in the nature of a demonstration. The developed farms were to serve as concrete examples of how the average settler should develop and manage his farm to be most successful.

The authorization by the 1919 legislature to establish so-called demonstration farms carried with it the stipulation that the project had to demonstrate its feasibility within approximately five years. To accomplish this end only three demonstration units were constructed, one at Independence in 1920, one at Roseburg in 1921, and one at Pineville in 1922. Although all three units were improved, equipped, and operated under the heavy handicaps of the comparatively low purchasing power of the farmers' dollar from the time the units were established, by 1923 the three farms were paying all

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operating expenses plus 5 per cent net on the investment in addition to the value of the farm living. The law that authorized this experiment has not been repealed but no additional demonstration units have been constructed to date (December, 1931).

DISABLED VETERANS' SETTLEMENTS

One other type of experiment to establish settlers on the land is represented by the so-called Veterans Bureau settlements. The responsibility for these settlements is primarily Federal, but State extension workers, agricultural experiment station personnel, and other State officials cooperated with the United States Veterans Bureau officials in charge of this work. The basic purpose of the settlements was to rehabilitate disabled ex-service men who had been awarded vocational-training pay of $100 or more per month for any period up to four years. Vocational-training pay was awarded on the basis of disability traceable to service in the Army or Navy.

In practically every State in the Union colonies were established or individual veterans were placed on farms. In no State did a plan of colonization take more positive form than in Minnesota. In this State attempts were made to establish six colonies of settlers; the Veteransville, the McGrath, the Orchard Gardens, the Moose Lake, the Bemidji, and the Silver Star settlements. All settlements were located in the cut-over area. Some of the land was raw cut-over land, some was swamp, and a small portion was improved upland.

The land was sold direct by owners to the veterans at a price ranging from $15 to $200 per acre. No initial payment or only a small one was required. In certain cases the purchase of a tract of land involved the guaranty by the seller that credit for necessary improvements would be obtained for the veteran. The usual credit terms demanded by the sellers of land required the veteran to make monthly payments to retire principal indebtedness. Many mortgages were taken over by the Minnesota Department of Rural Credit (see pp. 58 to 59) through which loans were amortized over a period not exceeding 40 years with interest at 4½ to 5½ per cent plus 1 per cent on the principal payable semiannually.

The settlers had the so-called "vocational-training pay" of $100 per month to single men, and $135 per month to married men with no children, plus an additional amount for each child. In addition these veterans were furnished, free of charge, medical care, books on farming, farm tools and machinery, and other necessary farming equipment for the class of training authorized. Supervision and instruction were provided by men on the pay roll of the United States Veterans Bureau.

The theory of this plan of settlement was to qualify disabled veterans who chose farming as their vocation to carry on successfully the business of farming after termination of their authorized training period which varied from one to four years. However sound the theory of this plan, the working out proved to be an undeniable failure in Minnesota. According to C. P. Hibbard, manager of the United States Veterans Bureau in this region, a major reason for the failure of the colonies was lack of cooperation on the part of the veterans in training.

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The paternalistic policy of a public agency under which the settler was placed on the land led the average settler to expect all his problems to be solved for him by the Government without much, if any, effort on his part. Moreover several of the land-selling agencies took advantage of the settlers' lack of information and of the fact that the Government officials did not exercise close supervision of sales contracts closed with settlers. In June, 1930, Mr. Hibbard estimated that more than 75 per cent of the veterans placed in the six colonies had abandoned their holdings. Many of the settlers left their farms as soon as their period of training ended. Only a few succeeded in developing prosperous farming enterprises; otherwise the projects have been failures.

It is interesting that the results of the paternalistic policy involved in this type of settlement and in the various State settlement plans are similar to those obtained by many private colonization companies during and since the World War. In a study of the grubstake stages of land settlement in Wisconsin [13] it was found that less than half (48.2 per cent) of all settlers located in the colonization type of settlement succeeded in increasing their net worth after buying their farms as compared with more than three-quarters (83.5 per cent) of those settlers who bought farms in "shotgun settlements" during the same term of years.

The major differences between "shotgun settlements" and "colonization settlements" are as follows: In the shotgun type of settlement the settlers bought their farms from any of a number of land-selling agencies as the land in the settlement was placed on the market by different independent agencies, the compactness of the settlement was determined primarily through competition between land-selling agencies. No agency furnished any grubstakes to the settlers. If land in any one settlement was owned and held for sale by one agency, this settlement was also classed as a shotgun settlement, provided the settlers were placed on their own resources and no grubstakes or helps were offered by the land company or other interested parties. In the colonization type of settlement, one land company owns all or the major part of the land sold to settlers, and the company furnishes grubstakes on credit. These grubstakes may consist of all or any of the following: Farm buildings, tools, machinery, explosives, seeds, livestock, groceries; services of a field man to help solve problems to promote the establishment of local markets, to establish community social centers, and help in other ways. In other words, the policy at one time or another of companies classed as colonization companies, was to provide any or all the kinds of grubstakes the settlers may have asked for, as a business proposition, the settlers obligating themselves to pay all costs with interest for credit.

A somewhat similar study (*16, p. 50*) of land-settlement conditions made in the cut-over area of Michigan, Wisconsin, and Minnesota also shows that furnishing grubstakes to the settler may actually retard his progress. In the study of some 2,243 records obtained from settlers in all types of settlements the colonization settlements were put into two groups, intensive and extensive, the former repre-

[13] HARTMAN, W. A. GRUBSTAKE STAGE IN LAND SETTLEMENT. 1928. (Unpublished Doctorate Diss., Univ. Wisconsin.)

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senting a high degree of supervision and liberal grubstakes, and the latter the reverse. The remaining settlement areas were also divided into two main groups—those in which the purchases were made from several land companies, and those in which purchases were made from former settlers and other private owners. This division was made because there is usually some supervision when all land is owned and sold by one company.

These four groups may be looked upon as representing four degrees of supervision and aid, ranging from intensive in the first group to little or none in the last group. The results of this analysis are presented in Table 10.

TABLE 10.—*Progress record of settlers who purchased farms from certain colonization companies compared with records of settlers who bought farms from other selling agencies*

Item	Unit	Records [1] of settlers who purchased from—			
		Colonization companies		Ordinary land companies (16 areas)	Dealers and others (15 areas)
		Intensive type (6 areas)	Extensive type (4 areas)		
Beginning net worth	Index number	66.0	73.8	101.1	127.0
Beginning farm capital	do	80.9	79.7	104.5	114.1
Cash on hand after purchase	do	95.9	81.2	102.5	120.8
Area in purchase	Acres	65.8	61.0	81.6	85.9
Land in timber	Per cent	4.8	15.4	20.5	11.3
Area cleared at purchase	Acres	.3	1.9	4.1	5.0
Price paid per acre	Index number	101.3	115.7	96.5	97.6
Foreign born	Per cent	51.1	74.0	59.4	53.3
Settlers coming from farms	do	20.4	16.0	41.0	48.9
Paid on options and contracts	do	17.0	21.9	22.2	26.3
Paid on all conveyances	do	23.3	30.2	41.2	53.0
Proportion of beginning net worth paid on land	do	35.4	30.4	42.4	46.0
Net gain per year	Index number	87.2	95.9	105.7	106.1
Land clearing per year	do	106.6	74.0	107.6	108.0

[1] Base of index numbers and percentages is average for all settlers in the 41 settlement areas studied.

It is evident from the figures on beginning net worth and farm capital, that the colonization companies attracted settlers with extremely small resources, and that, compared with settlers who bought their farms from other agencies, fewer came from farms, a smaller proportion of land they bought was in timber or was cleared, they paid a higher price per acre, and the net gain per year was lower. In general, it appears that a weaker type of prospective settler is attracted by a paternalistic land-selling policy than is attracted by the agencies that sell land with no provisions for additional credit or grubstakes. In the one case beginning settlers are led to expect help in all difficulties that may arise, whereas in the other they know that they are dependent upon their own resources. Since farming, particularly during recent years, has been generally recognized as a precarious business at best, it follows that grief is likely to come first to those who endeavor to overcome obstacles by going deeper and deeper in debt rather than by working harder and harder to develop their farms with their own resources in addition to money earned by working for others.

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Any colonization agency, public or private, must expect criticism and complaint on the part of settlers who fail in carrying out any work, program, or policy advocated by the agency. This always occurs. Furthermore a few scattered complaints, whether just or unjust, inevitably lead to many more, and feeling against the agency soon runs high, however well intended its policies. Failure, monetary loss, blasted hopes, and wastage of labor follow in train (*4*). It is also probable that the more paternalistic the policy of the land-settlement agency the greater will be the loss to the settlers, to the agency, or both.

Policies to Aid and Promote Private Settlement and Colonization Projects

A number of States have interested themselves in aiding and promoting private colonization and settlement projects along several different lines. The authorized policies which are enforced, or lie dormant at least for the present, in the several States vary from offering plans, advice, and suggestions for developing a colony to promoting in a marked degree the reclamation of wet and arid lands.

Certification of Settlement and Colonization Company Plans

In Montana a law provides that all development and colonization company plans to develop specific tracts of land must be submitted to the commissioner of agriculture, State Department of Agriculture, for approval. If a plan of colonization is approved the company or dealer must give satisfactory assurance that it will not be changed to the detriment of the home seeker. Unfortunately, the effect of this law is limited by the fact that the commissioner of agriculture has no authority to prevent a project from being developed regardless of disapproval.

For example, in 1929 the commissioner disapproved three applications to develop projects in different parts of the State, but in each case the company proceeded in spite of the disapproval. In each of the three cases the project was disapproved, not because the proposed agricultural development was not found to be feasible but because the proposed selling policy was not considered fair to the prospective purchaser. The project in Park County was disapproved because of inadequate credit terms and the other two projects (one in the Flathead Indian Reservation and the other in central Montana) because the proposed selling price was believed exorbitant.

In Utah and Idaho it is the duty of the commissioners of immigration to inform themselves about farming opportunities and to use all facilities at their command to encourage and promote desirable private colonization enterprises. In Utah the commissioner, under this law, cooperated with the Mormon church in locating farm colonies. The law in Idaho grants power to investigate any advertisement pertaining to colonization or settlement and to warn home seekers against inaccurate or misleading statements contained in any material sent out by promoters or others. The commissioner of immigration was also authorized to investigate any case where fraud was practiced by land-selling agencies and, if the facts justified, to prosecute. The legislature passed this law in 1919 but no funds were ever appropriated to make it effective. Such inquiries concern-

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ing land-settlement problems or opportunities as reach State offices are turned over to the Idaho State chamber of commerce for reply.

Possibly the most noteworthy legislation concerning certification of lands held for sale and the conditions under which the lands can be sold is represented by the Michigan land certification act (*29*). The act provides

> for the certification of the unimproved land and improved farms in the State of Michigan, the creation of a list of accredited dealers in lands, the examination of those qualified to certify lands, and the authorization to prescribe rules and regulations necessary to comply with the provisions of this Act and provide for a penalty for violation of the provisions of this Act.

Under the land certification act, certified land

> is land which has been or shall hereafter be examined, surveyed, and reported upon under the direction of the State Department of Agriculture and has been or shall be certified as suitable for some agricultural purpose.

The State department of agriculture is authorized to supervise the execution of the act, to make necessary regulations, and also to list accredited dealers who agree to confine their selling of unimproved lands in Michigan to certified lands, and to conform to the act and the rules of the department of agriculture of the State.

The act stipulates that examiners who certify the land must have had 4 years of college work, 4 years of farm experience, and 1 year in field-survey work in the Lakes States; the examiners must be approved by a board consisting of the State geologist, the dean of Michigan Agricultural College, and the commissioner of agriculture.

Examiners are required to report on the land after an accurate examination during which they collect the data required by the State department of agriculture. The cost of the examination is paid by the person applying for certification. The certification issued by the State department, after reports and examinations have been completed, includes: A map of the area in 40-acre units, showing location, topography in general, all soil types, and points at which borings were made; location of streams, lakes, roads, shipping points, and such other information as will enable the prospective settler to judge the agricultural possibilities of the area. The certification also involves recommendations as to the best use for the lands. The particular types of farming adapted to those areas classed as agricultural are recommended. The original report is filed in the State department of agriculture; the dealer is supplied with one copy and may purchase duplicates at cost from the department of agriculture.

The law requires that the official statement and certificate must be shown in full prior to the execution of any contract to the person buying or contracting to buy certified land; and a certified copy of the certification and map must be attached to each deed or contract involved in any sale of certified land. Furthermore, the law requires that a copy of the certification and the official statement be filed in the office of the register of deeds of the county in which the land is located together with such maps and plans as may be of benefit to the public. All of these papers shall be open to the public.

The act provides that any dealer may apply for a reclassification of his lands after five years. No accredited dealer may transfer to a nonaccredited dealer any certificate or map concerning the classi-

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fication made. A nonaccredited dealer using any such certificate or map for any land other than that to which the certification and map apply is subject to punishment for fraud.

The State department of agriculture sought to induce all dealers to have their lands certified by giving publicity to those whose lands were certified. But this policy failed, and up to June, 1931, only six dealers had had lands certified. The first four tracts, totaling 14,190 acres, were certified in 1924 and the other two tracts, totaling 1,695 acres, were certified in 1925.

In other words, the land certification law has been dormant since 1925. Out of a total of 15,885 acres certified at an average cost to the dealer of 18 cents per acre, 8,772 acres were declared to be fit for agricultural purposes.

Almost undoubtedly the relatively high cost to dealers of having their land certified, particularly at a time when the demand for farm land had almost disappeared, had much to do with the failure of this law to accomplish its purpose, for the law is highly commendable in many ways. The State of Michigan is making great progress in conducting an economic survey of its land resources. When the resulting facts are made available at public expense the cost for certifying land in surveyed areas can be decreased or eliminated. Then such a compulsory land-certification law may perhaps be the bulwark of a sound land-settlement policy.

BOND CERTIFICATION

A further step has been taken by a few of the States. By means of different kinds of financial aid in the form of State certification of bonds issued by private development companies or legally organized reclamation districts these States are enabled to promote and, in certain respects, to regulate the development of land.

One of the most interesting of these experiments grew out of the passage of a State mortgage association law by the Wisconsin Legislature in 1913. The law is designed to promote and direct the settlement of land in the State. Under this law any number above 14 of adult resident freeholders may associate to establish a land-mortgage association. The aggregate amount of capital stock of the association may not be less than $20,000.

The association has the power to: (1) Make loans on first mortgages upon improved or partly improved agricultural real estate up to 65 per cent of the appraised value of the land; (2) purchase first mortgages against improved or partly improved agricultural lands in the State from persons or firms or corporations engaged in the settlement or colonization of Wisconsin lands to whom such mortgages were issued; (3) issue bonds secured by the pledge of the mortgage taken or purchased up to an amount not exceeding twenty times the capital stock of the association. Each mortgage purchased by an association must be on the amortization plan maturing in not less than 20 years, must be a first lien on the property involved, and must not exceed 15 per cent of the association's capital stock and surplus in one loan.

The association accepts first mortgages on the settler's land either for payment on the land or for advances of cash for improvement

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or equipment. When the association wishes to liquidate this credit and to raise money by means of a bond issue, it deposits with the State treasurer as security for the bonds the individual mortgages up to the amount of the bonds.

The date, amount, interest rate, and other features concerning the bonds the association may wish to issue are subject to the approval of the State commissioner of banking. If the proposed bond issue is approved the proceeds of the bond sale are then available for further advances by the association. The law stipulates that the aggregate of bonds issued shall not exceed twenty times the capital stock and surplus of the association and that individual mortgages held as security by the State treasurer can be released only by substituting other approved mortgages in equal amounts, cash, approved bonds, or certificates of deposits. Before any mortgage is accepted as security the law requires that the State commissioner of immigration, acting under the commissioner of agriculture, must approve, after careful investigation, the value of the farm property secured by the mortgage, the condition and terms of the mortgage, and the plan of colonization or settlement in cases in which mortgages have been purchased from land-colonization companies. A favorable report by the loan committee of the association presenting the mortgage as collateral to the State banking commission must also accompany each mortgage. In addition to these precautions to prevent poor loans, the law requires double liability of stockholders in associations and close supervision of the business of the association by the State banking commission.

Like many of the laws enacted by different States to promote and direct land settlement, the Wisconsin State mortgage association law is commendable in theory but difficult to administer in practice. Two State mortgage associations, known as the First Wisconsin Mortgage Association and the Second Wisconsin Mortgage Association, were organized and operated under this law. The one association loaned $760,280 on 336 farms representing a total area of 22,090 acres. Two colonization companies issued and held all but a few of the mortgages used as collateral for bond issues. The second association loaned $444,000 on farms sold primarily through one other company. No business has been transacted by either association since 1925; the first one went into the hands of receivers in 1928 and the second one is trying to liquidate voluntarily. Both failed to accomplish the ends sought.

The failure of both is ascribed by the State banking commissioner to the fact that the farms secured by the mortgages used as collateral had been too highly appraised by the land companies issuing the mortgages. Over-optimism on the part of the associations underwriting the mortgages is explained, in part at least, by the fact that the associations were dominated by a few companies whose major interest was selling land. Although the law had not been repealed by the legislature up to June, 1930, the commissioner of banking did not expect any new associations to be authorized under it.

In summary it is to be remembered that a law of this kind is praiseworthy in many respects. In fact, the major weakness was not so much in the law itself as in its attempted administration while basic facts were lacking about the capacity of different types

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of land, in various localities, to carry specific debt loads. The risk in placing comparatively liberal farm mortgages is necessarily great when a constructive, broad-visioned land-use program has not been formulated. This is especially true anywhere if farms are undeveloped, or are only partly developed, as in the cut-over area of Wisconsin where the two farm-mortgage associations attempted to become established.

In the development of those sections of the West in which irrigation is necessary, the difficulties and expense of irrigation enterprises gradually become too large for most individuals. The returns from reclaimed lands became too slow and too uncertain to attract outside private capital. To continue the reclamation of arid lands, it became necessary to establish an organization that could claim the guarantee of State law behind it. The irrigation district was one of the outgrowths of this situation.

Utah enacted the first irrigation-district law in the United States in 1865. This law did not contain the provision for issuing bonds to provide funds for construction but provided for taxing the land to pay construction charges. In 1887 California passed the first irrigation-district law that contained a provision for issuing bonds as a lien on the lands within the district. Idaho, in 1897, enacted a law requiring the State engineer to examine and make an advisory report on the plans of each district prior to a bond election in that district.

California, in 1913, enacted the first legislation for State certification of district bonds. The main lines of State supervision and backing in irrigation districts consist of: (1) Authority to organize, (2) authority to issue bonds, (3) requirement that a State official must report on the feasibility of proposed projects, and (4) State certification of bonds. The problems involved in irrigation-district finance and the statutes of the States concerned with irrigation-district organization and finance can be noted in only a general way.[14]

The policy of State certification of bonds has tended to make them more attractive to outside capital and to make it more difficult for bonds of undesirable districts to find a market. Incidentally, the policy has given the States a measure of supervision over construction and expenditures.

Of the 12 States providing for bond certification the provision in 5, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas, merely means that the issuance of the bonds in question was in conformity with the laws of the State. But in the 7 remaining States, Arizona, California, Colorado, Nevada, New Mexico, Oregon, and Washington, bond certification signifies further that the feasibility of the engineering works has been favorably reported by State officials charged with this work by the laws that authorize bond certification. Utah, Montana, and Idaho, are 3 States in which bond certification laws, based on feasibility determination, were repealed. The Utah Legislature acted in 1923 and the Montana and Idaho Legislatures repealed the law in 1929. Lack of adequate investigations to determine the feasibility of proposed projects before certification, and the misleading nature of State certification on

[14] For further information see U. S. Dept. Agr. Misc. Pub. 103 (*21*) and Dept. Circ. 72 (*19*).

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bonds, without the State assuming financial responsibility, were the underlying causes of repeal by these States.

In the seven States providing for bond certification after determination of engineering feasibility the salient points of the law are similar. Upon application of the directors of a district for bond certification, State officials investigate: (1) Adequacy of water supply and water rights, (2) fertility of the soil and its adaptation to irrigation, (3) feasibility of the existing or proposed irrigation system to distribute water and the general condition of the construction of the project, (4) market value of the water, (5) market value of the land within the district, (6) relative aggregate amount of the bond issue and its proportion to the market value of the land, and (7) legality of the bonds. The aggregate amount of bonds certified may not exceed 60 per cent of the estimated market value of the irrigable land and irrigation works in Arizona, California, and New Mexico, nor 50 per cent in Nevada, nor 30 per cent in Oregon. In Colorado and Washington no percentage is specified in the law. The Washington law, however, stipulates that the proposed bond issue must be both necessary and adequate.

If the report of the investigation is favorable, the State must certify the bonds. After certification, State officials are required to supervise expenditures of the funds derived from the sale of the bonds and to inspect construction work.

The basic purpose of State bond certification was to improve public confidence in irrigation bonds as sound investments for savings and trust funds. Such certification undoubtedly facilitated the sale of more bonds on better terms. But the failure, during the past 10 years, of various projects for which bonds were certified has almost unquestionably decreased public confidence in State-certified irrigation-district bonds.

There is some justification for this decreased confidence in view of the fact that no State that certifies bonds either makes, or provides for the making, of such investigation as would determine, within the limits of predictability, the economic feasibility of the districts involved, and the engineering feasibility of the projects. Many ill-advised undertakings could be prevented and public confidence in the bonds might be restored, if compulsory bond-certification laws required that an unbiased analysis of the districts declare them economically feasible before State bond certification occurred. Such a law would also operate so as to approve only those districts on which the average settler could develop a profitable farming enterpise.

Although certain States are much inclined to consider subsidizing old projects and developing new projects regardless of the demand for or comparative advantages of producing and marketing similar crops in other parts of the country at a smaller cost, several States view existing conditions and settlement potentialities more broadly. The work of the State engineer in Oregon illustrates a newer philosophy. A survey of State-aided projects made by his office resulted in classifying 13 projects as feasible from the standpoint of soil fertility, water supply, transportation, and markets for products, provided the existing indebtedness of the 13 projects, representing $7,000,000, is refunded for $3,895,000. The work since 1923 of the

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division of reclamation of the department of conservation and development in the State of Washington has been not to promote the development of new projects but to resurvey existing projects that are in financial distress in order to formulate rehabilitation programs on the basis of a capitalized value determined in the light of a conservative estimate of productive returns.

DRAINAGE PRACTICES IN RELATION TO SETTLEMENT

It is estimated that about 15 per cent (91,500,000 acres) of the possible crop land of the country not now in use must be drained of surplus water before it can be used for cultivated crops. The reclamation of large tracts of wet land owned by different individuals or concerns involves a multitude of problems which can be handled most advantageously by the State or Federal Governments or by cooperation between the various owners.

To meet these problems and thereby encourage the reclamation of wet land the States with large acreages of undrained land have enacted laws providing for the organization of drainage districts. In substance, drainage-district laws aim to provide means (1) to distribute costs equitably among landowners and to collect such costs under special tax laws, (2) to finance the necessary construction costs by authorizing bond issues, and (3) to obtain through condemnation proceedings (eminent domain) any property needed to establish the drainage works and make the district a "going concern."

The general legal policy to organize a district does not differ materially in the separate States. A majority of owners, or owners of a majority of acreage, petition the county officials for authority to organize a drainage district. After organization, a board of supervisors is elected from the body of owners. The board of supervisors has legal authority to transact all business of the district. The expenses of organization and bond issues are paid by means of a drainage tax levied on the land benefited by the project. Usually the tax is graduated according to the benefits received from the improvements.[15]

The area in organized drainage enterprises in 1930 was 84,408,093 acres or 28.9 per cent (18,913,055 acres) greater than it was in 1920 (*38*). The investment in the 67,927 enterprises from which data were obtained in the 1930 census totaled $680,732,880. The lack of adequate public supervision, or of the authority and resources of any specific State office to determine the economic feasibility of proposed projects and to permit the organization only of those proposed districts found to be economically feasible, is suggested by the fact that more than one-third (35.5 per cent) or 29,980,516 acres of land in organized districts is unimproved and that many districts are financially embarrassed or defunct. House Report No. 2169, 71st Congress, 3rd session, on S. 4123 (*37, p. 4–8*), which proposed Federal loans for the relief of drainage districts illustrates the situation:

> The demand for relief for drainage districts comes from a farm population of approximately 5,000,000, which, according to the census of 1920, lives within these drainage districts.

[15] For detailed discussion of statutory provisions in the various States see Farmers' Bul. 815 (*45*), rev. 1927, and Dept. Bul. 1207 (*6*).

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These 5,000,000 are, for the most part, small farmers. The average size of their holdings is about 65 acres. They have their all invested in their farms. In some districts, it has been shown to your committee, thousands of farmers have lost everything because of their inability to meet their drainage taxes. In some areas 60 per cent of the farm population has been dispossessed, their land having been taken for taxes.

Such legislation falls in the class of promotional legislation unless it carries adequate regulatory measures and resources necessary for their enforcement. Existing conditions in drainage districts show the lack of broad public policy when the districts were organized. It would be sound public policy to conduct investigations of existing distressed districts (1) to determine the adequacy of the existing engineering works designed to reclaim the lands within the districts, (2) to determine the type of farming or other use of land which probably will prove most profitable, (3) to establish standards for determining the present and prospective productive capacity of the land resources and the capitalization they are capable of carrying, (4) to formulate an equitable program of financial reorganization or other adjustments necessary to place the district on a sound economic basis, and (5) to underwrite only such indebtedness as can be carried safely by the projects in question when in competition with lands in other parts of the country on which the same or substitute crops are grown.

If the rehabilitation of districts in financial straits is to be effected, there must be a willingness on the part of farmers and bondholders to abide by the results of an unbiased analysis by a public agency of the factors involved. In the future the undertaking of projects doomed to failure may be prevented by legal provision for such official investigation before authority is granted to organize a district.

POLICIES TO FINANCE THE SETTLER

Credit is usually vital in promoting land settlement, and the credit requirements of new settlers are different from those of farmers in established farm areas. The new settler, like other new farmers, may need credit assistance for part of the purchase price of the land, for operating machinery and tools, for work animals and other livestock, and for family living expenses. In addition, he needs credit to provide permanent improvements including house, barn, sheds, fences, a well, roads, etc., and for clearing, draining, or preparing for irrigation, in the course of getting the land ready for cultivation.

The amount of the loan and the rate of the interest are dependent upon the security the settler is able to offer. The purchaser of land in a developed area comes to a farm that has usable permanent improvements; all land, except that which for the time may be regarded as waste land, is in condition to be used for crops or pasture; the farm is ready to carry dairy cattle, beef cattle, hogs, poultry, or other livestock to its full capacity to furnish feed. The operator can use his full time in crop and livestock production. Such a farm offers as security for loans improved land of known producing capacity, permanent improvements, crops for crop liens, livestock for chattel mortgages, and machinery and tools for either liens or mortgages.

But a purchaser of undeveloped land comes to a farm that has no permanent improvements; has only a very small acreage or none

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ready for crops and pasture; and has a carrying capacity for livestock limited by lack of crop land for winter feed and in some cases by shortage of summer pasture. Much of the operator's time must be spent in erecting buildings, making other permanent improvements, and reclaiming the land. A comparatively small part of his time can be devoted to the production of crops and livestock. The returns he receives are small and slow. The security offered by such a farm consists of unimproved land of uncertain producing capacity and with no permanent improvements, a small assortment of machinery and tools, and a few head of livestock for chattel mortgages. The acreage of crops for crop liens is practically negligible. The settler is likely to be a stranger to his neighbors, and the money lenders are unacquainted with his financial soundness, his trustworthiness, or his ability as a farmer.

Creditors are reluctant to risk having the farms thrown on their hands, because the sales value is likely to be low, and the opportunities to sell are not numerous because unsold tracts remain in the hands of the selling or development companies who compete for all buying prospects. Sources of credit in an underdeveloped community are usually limited to local banks, local money-lending companies, and land-settlement companies. Personal sources, such as the relative who loans on easy terms, the farmer owner who finances the purchaser in order to make a sale, the banker who builds up a clientele by picking out promising young men and providing capital for larger business, are not usually found in a pioneer settlement. Business is insufficient to warrant the establishment of an organization to grant long, easy terms of credit. It is difficult to form cooperative borrowing organizations because the settlers are scattered and nearly all of them are poor. Unwillingness to assume joint liability for a loan to a stranger whose business ability, skill as a farmer, and honesty are unknown is a further drawback to establishing cooperative credit institutions.

Some land-selling agencies and money lenders, who have facilities for reselling, often grant the new settlers more credit than the property can reasonably bear and then recover by charging high rates of interest and an overvaluation price for the land. Because the man who buys a farm in an undeveloped area is frequently a poor risk, he is likely to receive credit only at high rates of interest and for short terms. If he fails to meet payments, the debt is likely to be foreclosed.

Recognizing the need for giving financial assistance to farmers already on the land, as well as to prospective farmers who required liberal credit, several States, during or after the World War, made experiments of somewhat different type from those hitherto considered. Several of the sparsely settled Western States and a few of the Eastern States loaned part of their permanent State funds on agricultural real estate, while other States provided special funds for agricultural loans. State loans on farm property are, in general, less conservative than are private loans and loans drawn from the joint-stock and Federal land banks. Settlers are usually better able to meet the requirements of State loans or, if unable to do so, the States are likely to exercise considerable leniency about foreclosing.

A relatively large amount of State funds has been loaned to individual farmers. The loans have been granted under different terms

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and have varied in conservatism according to State regulations and to the nature of the funds loaned. But the loans are all granted for the same purpose and may not legally be used otherwise. The purposes of the loans are for part payment on the land, for purchase of equipment including necessary livestock, for buildings and other permanent improvements, and for liquidating indebtedness.

The States that have enacted laws authorizing such loans are located, in nearly all cases, long distances from sources of easy credit and moderate interest rates. They have comparatively small populations and large areas of unsettled land. The systems were designed to provide for farm loans on easy terms, at the lowest possible rates of interest, without the necessity of renewal fees and commissions at stated intervals.

The State loans resemble the Federal farm loans, but do not duplicate them. The Federal farm loans are granted up to 50 per cent of the appraised value of the land and 20 per cent of the appraised value of the insured, permanent improvements. The State loans, however, usually represent a higher percentage of appraised values. No State loan, except under the Wisconsin mortgage association law, requires a local association of borrowers; neither are the borrowers required under the State laws to buy any stock in the loan fund. Many of the borrowers regard these as advantages over the Federal farm loans.

The sparsely settled Western States were chiefly the ones that engaged in experiments to grant State credit to farmers during or immediately following the World War. The agricultural depression beginning in 1921 came on the heels of several dry seasons in the West, and the borrowers in a large number of cases had great trouble in meeting their payments. Since the several States were anxious to hold their settlers and to avoid having large areas of land become idle by being thrown back on the hands of creditors, the State agencies administering the loans found it necessary to formulate such policies to deal with delinquencies as would prevent such a situation.

But the practice of making a liberal credit policy more liberal did not solve the problems. An apparent lack of conservation, a lack of determined attempt to mobilize such facts as were available for indicating the probable course of events, as well as an inability to predict the future approximately, destined many loans to foreclosure in practically every State that provided special rural credit. A summary statement of the results of the major experiments in the field of rural credit by various States follows:

Of the 12 States that were, or are, engaged in the farm-mortgage business, South Dakota has probably had the most costly experience. Aside from loans made on foreclosed farms which had been resold, only three loans had been made between 1925 and April, 1930; the policy at that date was to liquidate or salvage the business of the rural credit board. Up to April, 1930, bonds representing $3,412,000 had been paid off out of a total issue of $47,500,000, and a special State tax of $1,000,000 annually had been levied to check a growing deficit. The State is pledged and legally authorized to pay both principal and interest on outstanding bonds. Out of a total of 12,121 loans made, 2,470 had been foreclosed and 498 were in process of foreclosure. That the board was having difficulty selling farms

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obtained through foreclosure was evident in the fact that only 122 foreclosed farms had been sold since 1923—the date of the first foreclosure.

Some success is being had, however, in leasing these foreclosed farms. The board has divided the State into 18 districts, each with a field man in charge of farm-improvement work, supervision of farm operation, and sale and lease of farms owned by the State.

Just how much the State is likely to lose through its experiment in the field of rural credit is unknown. That the loss has been great and will be larger is not questioned. The attractive picture of a large influx of settlers because of liberal credit terms, and great progress and prosperity, painted by the proponents of the State rural credit system has not materialized (7). Instead the State is saddled with a relatively heavy debt as the result of its experiment.

Although a few States are still making certain select new and renewal loans, Minnesota and Oklahoma are the only two still actively engaged in the farm-loan business. Up to March 1, 1930, 10,158 loans representing $46,876,400 had been made under the rural credit act in Minnesota. At that date payments on 1,644 loans totaling $384,508 were delinquent one or more times, and 1,302 farms representing $8,271,477 in loans had been taken over through foreclosure. In addition to those represented by these foreclosed farms it has been estimated that there will be 1,000 to 1,500 more foreclosures by the end of 1932. A joint legislative committee appointed to investigate the department of rural credits found that the loans made since the department was reorganized in July, 1925, have been very conservative and that the majority of foreclosures have been and will be on loans made before 1925.

With respect to the future lending policy of the department of rural credit, the committee said:

> It is the opinion of a majority of the committee it should continue to make loans, but only on a very conservative basis. It would be impossible to liquidate the Bureau in a quarter of a century, hence it is believed the organization required to conduct the business may be used to continue the effort to perform the function for which it was intended. We are in and can not get out.
>
> If lending is to be continued the greatest care should be exercised in making appraisals, loans should be made only on improved farms and to thoroughly efficient farmers.[16]

The department of rural credit is no longer just a money-lending agency of the State as was originally intended. It is now a land-owning, farm-operating, and real-estate marketing institution which is losing money. With the prospect of owning some 3,000 farms by the end of 1932, the business of farm sale and management will become as important as, if not more important than, the lending of money.

It is the policy of the department to get all foreclosed farms ready for sale or rent. Some of the foreclosed farms have been improved and resold. It might be said that the department is in the farm-improvement business; tractors and other farm machinery are bought,

[16] Report to the president of the senate and speaker of the House by the joint committee of the Minnesota Senate and House of Representatives authorized and directed by Concurrent Resolution, dated Mar. 9, 1931, to make an investigation of the department of rural credit, p. 3, 6, 7. (Unpublished.)

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buildings are repaired or constructed, and the soil is being improved through a supervised cropping system. Through this system of farm improvement and efficient supervision of farm operations the officials of the department are attempting to salvage as much as possible from the unsatisfactory loans.

Oklahoma enacted laws providing for loans from permanent school funds, and from a home-loan fund. The home-loan fund represented a special appropriation of $320,414 by the legislature. Loans from this fund were made as second mortgages on farms against which the State held first mortgages. It was estimated by the officials in charge of the State loan division that in May, 1930, about 65 per cent of the 400 second-mortgage loans made had been foreclosed and that few of the remaining loans were in good condition.

On the other hand, the lending of school funds on first-mortgage security has been highly successful. Very few loans have proved to be ill-advised and the business of lending State school funds is increasing. Up to December 31, 1929, $31,174,506 had been loaned. During the last six months of 1929, new loans and renewed loans totaled $3,355,860.

The rural credit law in Arizona was repealed by the 1929 legislature. The major portion of the sum loaned under this law was placed in first mortgages on land in the Lyman irrigation district which is now financially defunct. The project had been overcapitalized and, according to State officials, the supply of water has never been large enough to irrigate more than 1,500 of the 6,000 acres included in the project.

The administrative policy under the law in Colorado is to grant no new loans, but to renew a few exceptionally good loans made under the old law. Up to March, 1930, a total of $960,000 had been loaned; officials said it was not likely that this sum would be increased materially. Many State officials and others have taken the stand that the State should not compete with private loan agencies.

An accounting of Idaho's experience in lending money on farm property, as of May, 1930, showed 1,047 loans classed as good loans representing a total of $2,418,370; 76 foreclosed loans totaling $203,936; and six loans, totaling $24,366, which were in process of foreclosure.

No farm loans have been made under the Montana credit laws since June 30, 1922, but in 1927, the legislature passed a law providing that whenever a State farm loan, made prior to the act of 1927, becomes due or delinquent, the mortgagor may make application to have the loan converted into a 33-year amortization loan and mortgage at 6 per cent.

At the date of the last accounting of such farm loans, June 30, 1930, out of a total of 2,007 loans representing an investment of State school funds totaling $4,301,562 only 127 loans amounting to $217,686 were in good standing in their original form. The State had acquired title through foreclosure or quitclaim deed to lands under 1,880 mortgages totaling $4,083,876.

Both the State Bank of North Dakota and the State land commission are authorized to make loans on farm property in North Dakota. The former is still engaged in that business but the latter was not making loans at the time of this part of the study (April, 1930) because the fund for that purpose had been depleted.

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The State Bank transacted almost three times as much business and acquired less than one-third more farms than did the State land commission. Up to January 1, 1930, the commission had made 5,226 loans representing $11,127,934, and owned 450 farms totaling an additional investment of $1,045,800 as compared with 12,203 outstanding loans representing $31,357,200 plus 717 foreclosed farms owned by the State bank as of March 1, 1930.

In Oregon a rural credit fund was created through the sale of 4½ per cent bonds totaling $450,000. The last bonds were sold in 1917, and in January, 1927, all funds were represented in 236 loans, only 11 of which had payments of principal and interest in arrears. Since that date no new loans have been made. Figures as to delinquencies and loans in process of foreclosure are not at hand.

Up to May, 1930, the credit board in Utah had approximately 300 foreclosed properties representing close to $1,000,000. About half of these foreclosed farms are within three drainage districts located in Millard County where so much land has reverted to the county for nonpayment of taxes that it has been found necessary to close certain schools and to curtail expenditures in other ways.

Loans were being made by the board in 1930 but only on so-called first-class security. The policy of the department is one of cooperation and helpfulness toward the farmer. Borrowers anxious to make good are carried along for as long as two years in many cases without payment of interest on indebtedness. Foreclosure is enforced only when farmers are hopelessly involved in debt or when the farm has been abandoned.

Although the State of Wyoming has not discontinued making loans on farm-mortgage security the requirements that the borrower must meet have been increased. The loss to the State because of bad loans is negligible. Only $111,462 or 1.42 per cent of the total loaned ($7,843,100) was represented by foreclosed loans in September, 1930.

In addition to the experiment to finance land settlement under the State mortgage association law (pp. 50 to 52) the Wisconsin State Annuity and Investment Board is authorized to use the teachers' retirement fund to make first-mortgage loans on farm property. Up to January 31, 1930, $8,214,685 were invested in first mortgages on farm property. At that date the director of the board summarized the affairs of the board as follows:

> There have been 61 foreclosures since the law was enacted in 1921. Most of these were cleaned up before the farms went to sale, but on several we must soon begin action. It is hard to give a correct statement as to delinquent loans. Out of about 1,400 loans, about 75 are behind on interest; but not more than 25 will have to go to sale. The board has acquired 10 farms and these are being rented or operated by the State board of control. The board has not changed its policy of making loans, but has raised the standards, making it a little harder for applicants to obtain money.

LAND SETTLEMENT REGULATORY POLICIES

Real Estate License Laws

Settlers who move into parts of the country with which they are unfamiliar are at a disadvantage in judging the quality and productive value of the land they may wish to buy. This is especially true of raw lands with few or no cultivated spots to show how the land can be used. It is a well-known fact that many land-selling

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agencies are ready to play upon this lack of information to exploit the uninformed purchaser. In order to check this type of dealer many States have placed the business of selling real estate under State supervision or regulation by licensing dealers in real estate.

The movement toward State regulation of the real-estate business is comparatively new. The first real estate licensing law was passed by the California Legislature in 1917 and up to June, 1931, 27 States had such laws. A list of the States that have passed license laws and the dates these laws became effective are listed in Table 11. A law was formulated and was worked through a large number of State legislatures largely by the efforts of the National Association of Real Estate Boards.

TABLE 11.—*States that have passed real estate license laws, dates such laws became effective, number of complaints received, and total money refunded since enactment of laws*

State	Date laws became effective	Total number of complaints	Total money refunded
		Number	*Dollars*
Alabama	Jan. 1, 1928	[1] 29	[1] 1,022.00
Arizona	June 9, 1921	[1] 300	[1] 15,000.00
Arkansas	July 1, 1929	27	
California	July 27, 1919	[2] 3,761	[2] 1,146,498.43
Colorado	Jan. 1, 1926	17	
Delaware	July 1, 1927	13	300.00
Florida	Sept. 20, 1923	1.729	459,788.41
Georgia [3]	Jan. 1, 1926	[1] 86	[1] 6,500.00
Idaho [4]	May 5, 1921		
Illinois	Jan. 1, 1922	3,625	[5] 90,268.84
Iowa	Jan. 1, 1930	122	30,724.29
Kentucky [6]	July 1, 1924		
Louisiana	Jan. 1, 1921	[1] 440	[1] 100,000.00
Michigan	Jan. 1, 1920	6,460	[1] 4,000,000.00
Montana	July 1, 1921	[1] 71	
Nevada [7]	July 1, 1923		
New Jersey	July 1, 1921	7,981	362,940.14
New York	Oct. 1, 1922	2,902	
North Carolina [8]	May 1, 1927	[1] 171	
Ohio	July 16, 1925	[1] 1,589	[1] 321,118.39
Oklahoma [6]	Jan. 1, 1924		
Oregon	May 29, 1919	1,930	68,306.13
Pennsylvania	Jan. 1, 1930	145	
Tennessee [6]	Apr. 16, 1919		
Utah	July 1, 1921	[1] 35	
Vermont	June 15, 1931		
Virginia	Jan. 1, 1925	135	91,323.40
Washington	Apr. 7, 1926	98	
Wisconsin	Jan. 1, 1920	[1] 492	[1] 200,000.00
Wyoming	Feb. 8, 1921	[1] 175	
United States		32,333	6,893,790.03

National Association of Real Estate Boards, 1930 Supplement to Real Estate License Laws—Their Development and Results, Tables 1 and 3; and data obtained from Public Acts, passed by the General Assembly, State of Vermont, 1931, pp. 192–194.

[1] Approximate figure.
[2] 1928, 1929, and 1930 figures. No previous record.
[3] Applies to only 5 counties.
[4] County prosecuting attorneys handle complaints.
[5] July 1, 1929 to June 30, 1930.
[6] Law not now in operation.
[7] Applies to cities of 2,500 or more.
[8] Applies to 8 counties.

A model State real estate license law (*29*) was drafted by the general counsel of the national association and, as a result of this guidance, the essential features of the law as adopted in the various States are fairly similar. Every man who deals in real estate as a

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vocation is required to obtain a license from duly appointed public authorities.

To secure a license the real estate dealer must be vouched for by a stated number of freeholders in the township or county in which he wishes to do business. He must maintain a definite place of business and display his license there, and he must produce other evidence of bearing a good reputation for honesty, truthfulness, and fair dealing. Certain States require applicants for licenses to pass an educational test to demonstrate their fitness. Only a few of the States requiring tests insist on a written instead of an oral examination. To operate as a real-estate dealer without securing a license is made a criminal offense in all States that have such laws. Each real-estate broker and agent must pay a license fee and give a bond, ranging approximately from $1,000 to $2,500.

The following 11 violations of the law, recommended as causes for suspension or revocation of licenses in the model real estate license law, are written in whole or in part in the specific laws adopted by the various States:

1. Making any substantial misrepresentation, or
2. Making any false promises of a character likely to influence, persuade, or induce, or
3. Pursuing a continued and flagrant course of misrepresentation, or making of false promises through agents or salesmen or advertising or otherwise, or
4. Acting for more than one party in a transaction without the knowledge of all parties for whom he acts, or
5. Accepting a commission or valuable consideration as a real estate salesman for the performance of any of the acts specified in this act, from any person, except his employer, who must be a licensed real estate broker, or
6. Representing or attempting to represent a real-estate broker other than the employer, without the express knowledge and consent of the employer, or
7. Failing, within a reasonable time, to account for or to remit any money coming into his possession which belongs to others, or
8. Being unworthy or incompetent to act as a real-estate broker or salesman in such manner as to safeguard the interests of the public, or
9. Paying a commission or valuable consideration to any person for acts or services performed in violation of this act, or
10. Using the term "realtor" by one not a member of the National Association of Real Estate Boards, or
11. Any other conduct, whether of the same or a different character from that hereinbefore specified, which constitutes improper, fraudulent, or dishonest dealing.

Another important feature of the law in a few States is that a nonresident applicant must maintain an office in the State and sign an irrevocable consent permitting action to be brought against him in the township or county in which the cause for action arises.

In a few States the law is so administered as to provide a mutual protection among real-estate brokers and salesmen against curbstone vendors, dishonest dealers, and sharp practices within their own profession. In other States the law is used not only to protect the business but to protect the public from exploitation and to regulate the sale and methods of selling of undesirable real estate. The laws in these States provide for a board of appeals to which complaints may be brought. The fact that administrators of the law in the various States had handled 32,333 complaints and had caused nearly $7,000,000 to be refunded to purchasers of real estate between the enactment of the laws and the close of the fiscal year ended in 1930 demonstrates that the regulatory and protective functioning of the law is effective.

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In many States the administrators take great pains to advertise that the law is being enforced for the benefit of the public. The names of all dealers in good standing and of dealers whose licenses have been suspended or revoked are published. The public is informed that all complaints registered will be investigated, and if the cases warrant, steps will be taken to make adjustments and to prosecute for fraud.

The California law authorizes the commissioner to employ technically trained men to investigate any lands offered for sale for colonization or rural-settlement purposes and to publish reports of such investigations for the benefit of prospective purchasers. A false or fraudulent statement in an advertisement or publication used by the company carries a penalty of two years' imprisonment and/or a fine of $2,000 plus the option of revoking the real-estate dealer's license. That this section of the California law can be administered effectively is suggested by the fact that in April, 1930, the State real estate department issued a report of the activities of the Romola (Inc.), a development company, in which many of the statements as to possibilities of success were refuted. Action against this company was also taken by the United States Post Office authorities, and on September 3, 1930, a Federal grand jury in Los Angeles indicted 30 officers and employees of the company for using the United States mails to defraud. The findings of the State real estate department in its inspection of another development project, the Runnymede Finance Co., are summarized as follows:

> The general plan of The Runnymeade Finance Company in all of its operations has been to sell a lot and together with said lot to sell a certain number of chicks or laying hens, the plan being that the purchaser should make a certain cash payment down and monthly payments on the balance due on the land contract. The company would then house and care for the poultry purchased with the lot for a period of ten to fifteen years and pay to the purchaser 75% of the net proceeds from the operation of said poultry. It has been represented in literature and lectures that the purchasers might reasonably expect sufficient dividends from the operations of said poultry not only to complete the payments on the land contract, but also to leave a handsome dividend or profit to the purchasers of the units. Their operations to date have not shown a profit sufficient to justify this expectation. What the future may bring in this regard remains to be seen.[17]

A decision by the Wisconsin Supreme Court in June, 1930, is interesting as indicating the attitude of the court toward the limitation of the Wisconsin real estate license law. Action by the court grew out of refusal by the real estate license board to grant a license to a corporation (organized under the laws of Texas) to sell certain Texas real estate within the State of Wisconsin. On the basis of a hearing held in December, 1929, the board found that the applicant

> had failed to furnish this board with satisfactory proof of its trustworthiness and competency to transact the business of a real-estate broker in the State of Wisconsin in such manner as to safeguard the interest of the public.

The circuit court affirmed the findings of the board, but the supreme court reversed the decision of the lower court. Part of the opinion of the supreme court is as follows:[18]

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[17] BARNSON, S. INSPECTION REPORT ON RUNNYMEDE [PROJECT] FILE 5853. 4 p. 1930. [Mimeographed.]

[18] State ex rel. Progreso Development Co. *v.* Wisconsin Real Estate Brokers Board. 202 Wis. Rpts. 155.

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Courts should hesitate in compelling the issuance of a broker's license, which is in effect much more than a mere permission to sell real estate. It carries with it the commendation of the licensee as a trustworthy and competent broker upon whom the public has a right to rely. If the board grants licenses to untrustworthy applicants the public will be in greater danger of fraudulent practices than it was before the board was created.

It is evident from a perusal of the record that the board in this case construed the statute as authorizing it to investigate as to the soundness or unsoundness of the investments which the broker was proposing to offer to the public, and if in the opinion of the board such offerings were highly speculative it was evidence of untrustworthiness and that the board should for that reason deny the application.

We have searched the act in vain for any language which confers upon the board the power to make a determination as to the soundness or unsoundness of the investments which may be offered by the broker and to grant or deny a license applied for accordingly as the board finds the investments are sound or unsound. * * * From what is said it should not be inferred that we in any way criticize the motives of the board. It was quite evidently actuated by the highest ideals of public service and the result of its investigations may well be pondered by any person desiring to invest in lands of the character under consideration.

The adverse decision of the supreme court was based upon a lack of statutory provision in the real estate law, not upon the unconstitutionality of regulating developments found to be highly speculative or unsound. Although the court did not determine the constitutionality of a statutory provision giving a board such power, the possibility that such action would be declared constitutional suggests a further extension of real estate license laws for the regulation of land sales.

The limitations of regulation by competency and educational tests are yet to be declared by the supreme court. Although stringent educational requirements would tend to eliminate many abuses in the real-estate business, particularly with respect to the sale of farm land, the courts might decide that such requirements interfere with a man's right to follow and carry on his business and that they are unnecessary for protecting the public against fraud. Courts have already taken the strong position that it is a valid and proper exercise of the police power to protect the public from the dishonest broker, and it may be that in the case of land sales the courts will decide that lands may be required to measure up to certain standards before a broker may sell them.

Blue Sky Laws

There is no concerted movement to get various States to adopt a "uniform blue sky law" regulating the sale of speculative securities, but such a movement is beginning. In 1929 a uniform sale of securities act was drafted by the National Conference of Commissioners on Uniform State Laws. This act was approved by the American Bar Association. Copies of this act have been made available to the various State officials concerned with the administration of security laws, and it is the plan of the commissioners to mold existing blue sky laws into accordance with the provisions of the uniform act (*1*). With few exceptions, the old blue sky laws did not provide for regulating the sale of land regardless of the speculative nature of certain transactions. Securities to be regulated under the uniform act, however, include contracts, bonds,

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or stocks used as a means for selling land under what may be called investment contracts for cash or on the deferred payment or installment plan. Blue sky laws will regulate the sale of speculative securities made or issued to promote any enterprise or scheme to sell lands located outside of the State on such plans when the value of the securities depends on the future stipulation by the promoters of the enterprise to furnish irrigation, drainage, or transportation facilities, or other value enhancing utility or improvement.

A law that embodies such features will go far toward prohibiting or regulating "farm-it-by-proxy" projects, and other unsound or visionary but not necessarily fraudulent projects. The purpose of the statute is to regulate the sale of any security or investment contract, the value of which inheres in a right to participate in the proceeds of an uncertain venture, thereby protecting the public against imposition by concerns that capitalize the hope of future profits without any tangible assets of proven value.

The privilege of offering securities to the public in Missouri is not granted in any case when it appears to the administrator of the law, after investigation

> that the sale of such securities would work a fraud, deception, or imposition on purchasers, or where the articles of incorporation or association, declaration of trust, charter, constitution and by-laws, plan of business, or proposed contract contain any provision that is unfair, unjust, inequitable, or oppressive. Or where the investigation of the commissioner discloses that the issuer is insolvent (*31, p. 207*).

The Missouri Securities Commission, in December, 1928, rendered an opinion concerning the sales contract including an absentee ownership provision used by the Romola Co. (Inc.), a California and Arizona land-development project, which caused that company to refrain from selling its stock in the State of Missouri. The license of this company to sell its stock in Indiana was revoked by the Indiana Securities Commission on August 22, 1930, because the affairs of the company were found to be in an unsatisfactory financial condition and because the statement, "This is a speculative investment" was not written in a conspicuous place across the face of each stock certificate sold in the State as was ordered by the securities commission at the time license was applied for.

There is little question but that real-estate licenses and blue-sky laws have essential parts to play in any constructive land-settlement program. The effectiveness of such laws in directing land settlement is limited, however; (1) because of the difficulty of regulating the activities of land-selling agencies engaged in interstate business; and (2) because of the lack of basic facts as to the economic use of land resources for agricultural or other purposes.

Possibilities of Federal Control

Partial results of a survey of interstate transactions of 1,258 active land-settlement and colonization companies in the United States revealed the fact that almost half (46.7 per cent) of the companies were selling lands in more than one State, and that slightly more than half (53.9 per cent) of those engaged in interstate business were conducting so-called home-seekers' tours. Even assuming that basic facts as to the economic potentialities of land were available,

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no State law could prohibit predatory land-selling agencies from transacting business en route between States.

To make a sale of land to a person living outside the jurisdiction in which the land is located, it is necessary to communicate with the probable purchaser via post office facilities and/or the facilities of interstate commerce (telegraph, telephone, transportation, etc.). Since these media are under the regulatory control of the Federal Government, the Federal Government has control of the machinery and channels through which the transactions must be consummated. Section 215 of the Criminal Code of the United States forbids the use of the mails for fraudulent purposes. This law has been applied so often in obtaining convictions in fraudulent cases that no new legislation of this character seems to be necessary. Lack of available basic facts relative to the economic use and potentialities of land, however, definitely handicaps enforcement of the spirit of the law in so far as land sales are concerned. For the most part, predatory land-selling agencies make a practice of avoiding specific misrepresentation and mere puffing and exaggerations carried through the mail are not within the prohibitions of the statute, but when a proposed seller goes beyond magnifying his opinion of the advantages which the land may have by inventing advantages and falsely asserting their existence, he transcends the limits of puffing and engages in false representations and pretenses which the statute denounces.[19]

The United States Supreme Court [20] interpreted the powers of Congress to regulate interstate commerce as direct and without limitations, stating that Congress may adopt means necessary and convenient and that these means may have the quality of police regulation. Thus far Congress has not passed legislation to regulate the sale of land under this authority. Although Congress could enact legislation to compel all concerns engaged in interstate business to operate subject to a Federal license to be issued only after the methods of operation have been subjected to careful scrutiny by Federal and State officials, it is highly improbable that such rather distasteful legislation is advisable.

Uniform real estate license and blue sky laws in the several States, together with the existing postal laws, may be adequate regulatory measures provided they are administered in the light of facts necessary to establish rural-planning programs. Without such facts it is doubtful whether all of the most fraudulent practices will be prevented.

LAND-USE PLANNING PROGRAMS

Conditions already described emphasize the need for land-utilization planning programs to promote those uses of land and methods of use that are both efficient and in harmony with the general welfare of the communities involved. Briefly, such a program, worked out through the cooperation of Federal, State, and county agencies, would result in a more economical utilization of land resources; would facilitate the elimination of unjustifiable school, highway,

[19] United States *v.* New South Farm Home Co., 241 U. S. 64.
[20] Hoke *v.* United States, 227 U. S. 320.

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and other local government costs and the social and economic loss resulting from scattered settlement on submarginal and marginal lands; would help legitimate land-settlement and colonization companies to plan their activities in accordance with sound economic facts; would make possible the establishment of valuable forest and game districts on lands which to-day are not used productively for any purpose; and certainly not least important, would provide a factual basis that would be very helpful in the administration of real estate, blue sky, and postal laws.

If the need existed in the past for a public policy adequate to accomplish that end, the policy did not materialize. Glowing accounts of how to expand the agricultural area, with little or no regard to the use for which the land was most economically adapted have been popular subjects for active discussion. In this period of general agricultural distress farmers are tasting some of the sour fruits of misguided past efforts to expand the agricultural area.

These many complex agricultural problems suggest the inapplicability of superficial remedies and the need for a comprehensive survey of the present and future prospects for agriculture. Although future prospects can not be predicted accurately, such a survey would probably provide the basis for formulating a long-time agricultural program which can be adjusted from time to time, in line with unforseen changes in economic events, with less economic and social loss than has occurred under the haphazard methods of the past. Land resources and soil, climatic, topographic, and other physical characteristics, are important factors to be considered.

Linked with this knowledge of the land itself must go an estimate of market opportunities. Land uses can not be indicated by production possibilities alone. These possibilities must be appraised in relation to specific market conditions. The best use for land is profoundly influenced, not merely by soil properties and climatic conditions, but also by technical progress in agriculture, by the development of competing areas, and by tendencies in the consuming markets. Ten years ago certain lands might have been adjudged well adapted to wheat growing which would now have to be assigned to other uses. Economic, rather than natural, conditions have changed.

A land-use planning program is especially needed in all parts of the United States in which there appear to be serious maladjustments in the use of land resources. Complete development of such a program calls for a thorough survey of physical, social, fiscal, and other economic factors and conditions. It also calls for an analysis of these factors and conditions in the light of regional, national, and even international tendencies and policies which directly or indirectly influence the use of land. It would seem, therefore, that the complete development of a sound land-use planning program in any area or region could be developed most effectively by coordinated efforts of local, State, and Federal agencies.

Considerable bodies of data, of varying degrees of usefulness in the development of this program, are already available for different parts of the country, but no uniform plan covering the work of the States and the Federal Government has been adopted. No attempt is made in this bulletin to discuss in detail the scope of the

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work of the Federal Government or of the various States to obtain such data, but in the following pages an attempt is made to point out the most important phases of such work of both governments.

Classification of Lands in Public Domain

The question of classifying lands has been before the public and before Congress more or less intermittently for more than 150 years, yet no adequate provision has ever been made for the type of land-classification study needed to cope with the agricultural problems resulting from the lack of a coordinated Federal and State land-use policy. With the exception of soil and topographic surveys, described later, the work of the Federal Government has been confined, in general, to the public domain.

The land ordinance of May 20, 1785, provided that mineral lands be separated from agricultural lands. Many comparable laws were passed in the next 80 years, but it was not until 1849 that Congress authorized the classification of agricultural or potentially agricultural lands into subclasses for the purpose of granting to the States all swamp and overflowed lands on condition that the States drain the lands and use the proceeds from sales for internal improvements. During the early period it was generally recognized that a classification of the land was a prerequisite for legislation concerning the disposition of the public domain, but adequate appropriations to carry on the type of surveys authorized were not made available.

The United States Geological Survey was created by Congress in March, 1879. The law provided, in part, that the director of the survey "shall have the direction of the Geological Survey and the classification of the public resources, and products of the national domain." One of the major purposes of the law was to authorize a classification of land and thus make it possible for the General Land Office to meet the requirements of existing laws in the disposition of the agricultural, mineral, pastural, timber, desert, and swamp lands.

This section of the law, as in the case of provisions in similar laws previously passed by Congress, was practically nullified because of lack of appropriations. Exposure of practices to alienate coal and oil lands under agricultural entry and recognition of the inapplicability of the homestead law of 1862 in the arid and semiarid lands in the West led to a classification of land administered under the stock-raising and enlarged homestead acts. But this classification is incomplete. The purpose is mainly to prevent the homesteader from obtaining timber or irrigable land or other land of which less than 640 acres are needed to support a family. In other words, although a wealth of information of great value to prospective homesteaders has been collected, it has been collected from the viewpoint of the official who must conform to the law in disposing of the land rather than from the standpoint of determining whether the land can be farmed profitably.

In addition to its work in passing on applications for entry under the grazing homestead act, the United States Geological Survey is making a more or less general classification of both public and privately owned lands in the public-land States. The classes are: Irrigated and irrigable land, farming land, farming grazing land, graz-

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ing forage land, grazing land, Missouri River bottom land, stony land, and national forests.[21] To date such classification has been completed in the central Great Plains and the northern Great Plains. This work is far superior to any previous land-classification work carried on by that organization, even though no measure has been made of the various factors determining the economic use for which lands are best adapted.

Topographic Surveys

The organic act creating the Geological Survey also provided for the making of topographic surveys and the preparation of topographic maps. Up to June 30, 1931, the area surveyed and mapped covered almost half (44.6 per cent or 1,356,988 square miles) of the continental United States (*28, p. 8*). During the year 1930–31, 21 States, 2 counties, and Hawaii, cooperated with the Geological Survey in mapping 18,283 square miles. The thousands of maps issued as a result are graphic engineering reports essential to the study of drainage areas, irrigability of lands, possible power development, and rights of way. These topographic data, along with the soils data and the climatic data obtained by the Bureau of Chemistry and Soils and by the Weather Bureau, United States Department of Agriculture, in cooperation with the various States, furnish fundamental facts needed in making an economic classification of land.

Soil Surveys

The purpose of the soil surveys is not to provide an economic classification of land but rather to obtain and present an essential basis for such a classification. The soil-survey maps and reports are of value to prospective buyers of land in a surveyed area. They show which soils are most productive and give the location and extent of the different soils in each surveyed county. Information gathered by the soil surveys constitutes an inventory of soil resources which, in accuracy, scope, and practical value, surpasses anything in existence elsewhere.

Soil-survey work has been conducted by the Federal Government in cooperation with the various States for more than 30 years. Up to June 30, 1932, detailed surveys covered 859,462 square miles and reconnaissance surveys covered 628,354 square miles (*23, p. 25*). This brings the entire area of soils that have been mapped and described by the Bureau of Chemistry and Soils of the United States Department of Agriculture to a total of 1,487,816 square miles or 952,202,240 acres.

Weather Reports

The Weather Bureau, of the United States Department of Agriculture has long been engaged in the systematic collection and presentation in daily, monthly, and annual reports in all parts of the country, of data concerning amounts of precipitation with averages for the period of observation, together with tables of snowfall, averages and extremes of temperature, averages of relative humidity, sun-

[21] Aldous, A. E., Deeds, J. F., and others. LAND CLASSIFICATION OF THE NORTHERN GREAT PLAINS: MONTANA, NORTH DAKOTA, SOUTH DAKOTA, AND WYOMING. 136 p., illus. 1929. (Autographed from typewritten copy.)

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shine, winds, days with precipitation, details of excessive rainfall, the dates of first and last killing frosts, length of growing season, and other weather phenomena. These data, along with the soil and topographic materials made available by the Federal and State Governments, are indispensable basic factors in the determination of the use for which land is best suited.

Land Classification for Taxation Purposes

North Dakota and Montana have special legal provisions for classifying land for purposes of making tax assessments. The Montana law provides for a classification of land as follows: (1) Agricultural land, (1–a) agricultural land susceptible of irrigation, (1–b) agricultural land not susceptible of irrigation; (2) irrigated and nonirrigated lands; (3) grazing lands; (4) timberlands and stump lands; (5) lands bearing stone, coal, or valuable deposits; (6) lands bearing natural gas, petroleum, or other mineral deposits; and (7) lands valuable for more than one purpose.

In North Dakota the law stipulates that lands shall be grouped into four classes: Class A, class B, class C, and class D, and that each class shall be divided into 10 subclasses, as A–1, A–2, A–3, etc. It also provides that the valuations for tax assessments on these four classes and their subclasses shall range from $1 to $2.50 per acre for the poorest land in the lowest group to $190 to $200 per acre for the best land in the highest group.

In making the classification, in both States, all recognized elements of value are to be taken into consideration, including proximity to market, topography, percentage of tillable area, and composition, nature, and fertility of the soil. Provision is made for reassessment should the value of land go beyond the set limit.

In both States the law provides that the work is to be done by counties under the direction of the county commissioners, but the classification is optional with the counties. Funds to meet the expenses of the classification are to be provided by the counties under authority to the counties to levy an annual tax, on all taxable property in the county, of 1 mill in Montana and one-fourth mill in North Dakota. The tax levy ceases automatically when a survey has been completed. In Montana the county commissioners initiate the survey, but in North Dakota the commissioners are required to have the land classified upon receipt of a petition signed by not less than half the resident freeholders of acre property in the county.

In Montana all lands in the county except vacant lands in forest reserves and Indian reservations, and unsurveyed lands, are classified; in North Dakota all acre property, except that used for rights of way by common carriers, whether taxed or not, must be scheduled and classified. In Montana the county commissioners of each county being surveyed determine upon a manner of classification. There is no central authority in the State to hold the boards of county commissioners to a uniform method of survey. In North Dakota the rules and regulations adopted by the county commissioners must be approved by the State tax commission and must be uniform throughout the State.

The classification authorized has not made much progress in either State. In North Dakota only three counties (Oliver, Mercer, and

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Dunn) had classified their lands by April, 1930, and the State deputy tax commissioner then stated that most counties were not, and probably would not, be inclined to pay for such a classification. A record of how many Montana counties classified their lands under the authorizing law was not available for this study. The State law does not require a classification that will be serviceable in directing land settlement, but several of the counties have made a qualitative classification of their agricultural land. This was done with special thoroughness in Fergus County, Mont. Since the county was the unit for this classification, the value of the completed work varies greatly in the different counties, and in many surveyed counties the cost of the work is said to exceed the value of the classification.

Michigan Inventory of Land Resources

One of the most thorough plans to obtain the basic facts needed to make an economic classification of land is represented by the inventory of land resources in Michigan. This work was begun in 1922 as a possible means to meet a number of land-utilization problems in the State. The purpose is to make

> an inventory of the present character and conditions of Michigan's land, forest and water resources, and to record the manner in which they have been affected by past use and abuse, in order to provide a basis for their more effective and intelligent conservation and development (*34, p.* 77).

The Michigan inventory of land resources is the first of its kind in this country. The work is administered by a separate division in the State department of conservation. The Bureau of Chemistry and Soils of the United States Department of Agriculture and various State offices cooperate in the completion of different projects included in the survey. Aside from work of the cooperators, the survey is financed directly through legislative appropriations.

Since this type of survey represented a pioneer undertaking, changes in technic and kind and quantity of data gathered have been necessary. At present, the survey covers the following projects:

1. Base map: A detailed base map which shows the townships, sections, railroads, roads, trails, lakes, streams, cities, farm houses, mines, quarries, lumber camps, resort hotels, summer cottages, hunting and fishing camps, etc.
2. Soil map: A detailed soil and lay of the land map which shows what part of each farm or section of wild land is sand, loam, clay, muck or peat and whether the land is level, rolling or steep and hilly. This work is carried on in cooperation with the Soils Department of Michigan State College and the U. S. Bureau of Soils.
3. Farm-forest map: A detailed farm and forest map which shows the kind of forest growth, its size and the density of the stand, together with the area of slash, burn, marshes and bogs, as well as the cleared land that is used for cropland, pastureland or orchards and the areas of apparently idle or abandoned farmland.
4. Timber inventory: A forest stand and growth tally to furnish data on (a) the volume of merchantable timber in the various types of second growth and virgin forest and (b) the rate of forest growth on the different soil types. This work is carried on in cooperation with the Lake States Forest Experiment Station.
5. Water power inventory: An inventory of the water power possibilities of the main rivers and streams that locate the existing water power plants and their capacity, the undeveloped power sites and the approximate amount of power that can be developed at each with an estimate of the cost of development.
6. Geological inventory: A map and report on the glacial and hardrock formations for the purpose of providing information that will assist in the location

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and commercial utilization of such geological resources as sand, gravel, clay, shale, limestone, building stone, marl, peat, and underground waters. This work is carried on in cooperation with the Geological Survey of the Department of Conservation.

7. Lake maps: A detailed map of the principal lakes to show the weed beds; nature of the shoal lake bottom, beach, and banks; location of cottages, summer hotels and resort subdivisions; together with the roads leading to the lake, the adjacent cleared land, and forest bordering the lake.

8. Stream records: Records on the character of the main streams and their feeders for width, depth, temperature, color of the water, rate of flow, degree of flooding and nature of the stream bottom.

9. Wild life tally: A record of the kind and number of game and predatory birds and animals sighted (or their signs) and the nature of the covert or habitat in which seen.

10. Economic study: An economic study covering trade areas and distribution of habitation, intent in land ownership, tax delinquency, state lands, distribution of wealth, and the nature of the country's business and production.

11. Land ownership: A land ownership map platted from the county records to show who owns the lands outside of the platted city limits and resort subdivisions (*34, p. 77–79*).

On January 1, 1930, field work and the publication of maps and reports had been completed or were in process of completion for the following sparsely settled counties in the northern part of the Lower Peninsula and in selected counties in the Upper Peninsula: Lower Peninsula—Alpena, Antrim, Charlevoix, Crawford, Kalkaska, Montmorency, Ogemaw, and Roscommon; Upper Peninsula—Alger, Chippewa, Iron, Luce, and Menominee.

All maps and reports concerning the survey are made available for free inspection at the office of the Land Economic Survey, State Office Building, Lansing, Mich. Copies of available maps and reports are obtainable for the cost of printing and mailing. Results are not analyzed for the purposes of formulating a State land policy. The survey is strictly a fact-finding organization and whatever policies may be developed on the basis of results obtained thereby must be developed by other State offices or other agencies. The materials are made available to the forest, game, park, and land divisions of the State department of conservation and to other public offices which have need for the survey data in planning their programs of work. The mass of data made available by the survey is useful in connection with blocking out State forests, parks, and other recreational centers. Prospective buyers of land in the surveyed counties can obtain valuable data concerning possibilities of developing profitable farming enterprises on various types of soil in different parts of the State in which they may be interested. The results of the survey would also furnish to county officials a valuable aid in assessing land for taxation purposes and in formulating other phases of a constructive land-use planning program. Up to March, 1930, however, no county board officially had tried to use these materials.

Although the survey furnished fundamental data needed in order to formulate a rational program of land utilization, no central State agency has authority or is attempting to correlate these data with other essential social, fiscal, and general economic facts in such manner as to direct settlement to lands best suited for agricultural purposes. Michigan will be in a position to set the pace for all other States in developing a sound State land policy as soon as such an agency is established.

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Inventory and Study of Land Resources in Wisconsin

In 1928, the State of Wisconsin began a land economic inventory in northern Wisconsin patterned closely after the Michigan inventory. The inventories differ somewhat in detail but the object of each is to compile facts concerning natural resources and to make these facts available to public officials and others who need them in formulating programs of work.[22] The Wisconsin statute (*44, p. 1116*), which grants authority to conduct the survey, is a general statute having as its objective the collection and publication of facts to attract immigrants and capital to the State. The subsection of the statutes referred to reads as follows:

> To cause to be collected and printed, in the form best calculated to attract to the state desirable immigrants and capital, information relating to the advantages and opportunities offered by this state to the farmer, the merchant, the manufacturer, the home seeker, and summer visitor. The publication shall be subject to the provisions of section 35.29 and shall be in the form of circulars, folders and pamphlets, and may be translated and printed in foreign language; to cause to be inserted in newspapers, magazines and farm papers, appropriate notices, and to maintain permanent exhibits in populous centers, if he shall determine that the best interests of the state will be advanced thereby.

The work of collection, compilation, and dissemination of the survey data is administered through the division of publicity, fairs and State development, State department of agriculture and markets, Madison, Wis. The various projects in the survey are conducted in cooperation with a number of agencies including the State department of conservation, the State department of public lands, the State natural history and geological survey, the State historical department, the State quartermaster's department, and the departments of agricultural economics, botany, zoology, and geography of the University of Wisconsin. The soil survey is made by the State department of soils in cooperation with the Bureau of Chemistry and Soils, United States Department of Agriculture. The fact that all of these organizations (particularly the State department of conservation in administrating its forest crop law, in establishing State forests and parks, and in promoting fish and game propagation) can use the survey data suggests that the survey has considerable practical value.

With respect to using such materials as a basis for formulating and establishing a coordinated Federal and State land policy, however, much remains to be done. After making a land-economics inventory in two counties (Bayfield and Vilas) the intensive type of land inventory was discontinued and the department of agriculture and markets cooperated with the college of agriculture, various other State offices, and county officials who were already engaged in conducting what may be called county emergency surveys.

These county emergency surveys grew out of a study of tax-delinquency problems in 17 northern Wisconsin counties, and an intensive study of land utilization in relation to tax delinquency in one northern Wisconsin county made by the Wisconsin College of Agriculture in cooperation with the United States Department of Agriculture (*17, 18*). These two studies pictured the various aspects

[22] For details concerning the Wisconsin land economic inventory, see Wis. Dept. Agr. Bul. 97 (*11*) and Bul. 100 (*12*).

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of land-utilization and tax-delinquency problems in northern Wisconsin and served as the basis for outlining immediate legislative and county programs of action to remedy the most evident and serious maladjustments in the use of land. They furnished the basis for recommending [23] the following lines of action:

I. The county to bid in all tax certificates (Get the good as well as the poor land in county ownership).

II. The county to sell no tax certificates to speculators in tax certificates.

III. The county to take tax deed title on all certificates when "ripe."

IV. The county to trade county owned land located outside of forest units for land in forest units unless owners of such land intend to practice forestry and not sell to unwary settlers or other "speculators."

V. The county to encourage scattered settlers to accept county owned land located in zoned farming areas for the land owned by such settlers in zoned forest areas, and if these settlers will not trade the county to buy them out with money which would otherwise be used for schools, highways, and other purposes within these forest areas. (Get all residents out of forest areas and decrease what otherwise would be necessary expense for roads, schools, etc.)

VI. The county land committee to take the necessary steps through the county board or state legislature to disorganize uneconomic civil town units. The basis for determining what combination of towns will prove most economical will have been established by the study made.

VII. The county land committee to cooperate with the state department of conservation to employ an experienced forester whose title might be "County Forester." This man to be the official forester of the county. His duties can be:

1. To inventory the forest cover on all tax delinquent land.
2. To establish and manage county forests.
3. To make arrests for trespassing on land against which the county owns one or more tax certificates. It might be suggested that much of this non-tax paying land has merchantable stock on it. By preventing trespassing on this land and saving this merchantable stock for the county, all or a larger part of the forester's salary and expense may be returned to the county when the forest crop is harvested.
4. To make arrests for violation of game laws.
5. To post all land in zoned areas; to direct settlers to agricultural areas; to help prevent sales in zoned forest areas to unwary settlers by private owner of land within these areas; to direct tourists to camping sites, resort centers, etc.; and otherwise promote the interests of the county.

VIII. The county land committee to be authorized to cooperate with similar committees appointed by county boards in all Wisconsin counties where tax delinquency and the resulting land use problems are in evidence. Such cooperation is essential to bring about a far reaching state land policy into which the work initiated by the various counties will materialize.

It was also recommended that immediate consideration be given to the feasibility of (1) establishing county forests; (2) enforcing (*a*) section 10, article 8, of the State constitution, which authorizes the State to buy land for forests, and (*b*) the statute which authorizes the State to buy tax-delinquent land from the county; (3) amending the school equalization law to prevent subsidizing poor school districts, the existence of which can not be economically or socially justified.

The county emergency surveys are distinctive in that: (1) They are made on request of the county board of supervisors; (2) the survey brings together, in a more or less general way at comparatively small cost, data concerning land-utilization problems in the county; and (3) the results are presented in special circulars de-

[23] HARTMAN, W. A. A SUGGESTED WORKING PLAN TO ZONE LANDS IN NORTHERN WISCONSIN. 1928. (Unpublished.)

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signed to help any county board to study its own condition and map out lines of action.

Up to June, 1931, the results of these emergency surveys had been published for four counties (Marinette, Ashland, Taylor, and Oneida) and surveys had been completed or were in process of completion in two additional counties (Forest and Washburn). One of the important results of these surveys is the tendency they may have to crystallize in the minds of public officials and others the serious nature of land-use problems and the need for adequate studies to develop sound land-use planning programs.

In addition to enacting legislation to give county boards power to establish county forests, and to grant certain other powers in connection with zoning rural areas for uses to which the land is best adapted, the Wisconsin Legislature recognized, in the following joint resolution, that the development of a sound land policy calls for coordinate action on the part of Federal, State, and local agencies interested in the welfare of the agricultural industry:

STATE OF WISCONSIN

Joint resolution relating to a national plan for land utilization and agricultural development

Whereas it is generally recognized that the present depressed state of agriculture is partially due to the uncontrolled rapid expansion of agriculture which has characterized the development of this country during the past century; and

Whereas the use of marginal and submarginal lands is one of the factors in the overproduction of practically all agricultural products, which can be remedied only through the abandonment of attempts to farm these lands and their devotion to such uses as forestry, grazing, and recreation, to which they are naturally better adapted; and

Whereas it is evident that agricultural recovery depends to a very great extent upon more intelligent planning with regard to the uses of lands, and there is urgent need that immediate steps be taken to this end; Now therefore be it

Resolved by the assembly (the senate concurring), That the Legislature of Wisconsin respectfully petitions the Congress of the United States to take immediate steps for the development of a long-time policy of land utilization and balanced agricultural production. To this end the United States Department of Agriculture, in cooperation with the several States, should be enabled to make comprehensive economic surveys of marginal and submarginal lands now devoted to agriculture to determine the uses to which they could be put to best advantage, and appropriations should be made for the development of forestry and recreational opportunities on such of these lands as are more suited to these purposes than to agriculture; be it further

Resolved, That the Congress at once take steps to withdraw all public lands from homestead entry unless detailed soil and economic surveys give conclusive evidence that such homestead entry promotes the welfare of the agriculture of the Nation, not just the State in which the homestead land is located; be it further

Resolved, That the Congress appropriate no more funds for irrigation or land reclamation projects unless it can be clearly shown that the results to be obtained from such appropriations are in accord with a sound long-time policy of land utilization and a balanced agriculture for the Nation as a whole not just the area in which such appropriations are asked to be spent; be it further

Resolved, That properly attested copies of this resolution be sent to the President of the United States, to each of the two Houses of Congress of the United States, the Secretary of Agriculture, and also to the agricultural department of each of the several States.

Henry A. Huber, *President of the Senate;* R. A. Cobban, *Chief Clerk of the Senate;* Chas. B. Perry, *Speaker of the Assembly;* C. E. Shaffer, *Chief Clerk of the Assembly.*[24]

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[24] Cong. Rec. 75 (2) : 1284.

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Minnesota Land Economic Survey

A large and increasing area of tax-delinquent and abandoned land, primarily in the cut-over area of Minnesota, resulted in the 1929 Minnesota Legislature authorizing and directing the State department of conservation to make a land-economic survey of all lands in Minnesota (*30*). The act stipulated, in section 1 thereof, that "said survey shall first be made of lands in the so-called forest area of northern and northeastern Minnesota." The failure of the 1931 legislature to appropriate funds for this survey has limited the extent of the survey made to the one county, Hubbard, surveyed out of funds appropriated for this work under the act providing for the survey.

Three types of data—forest, soil, and economic—were inventoried for Hubbard County. The United States Forest Service cooperated with the State in mapping forest-cover types and obtaining timber volume and growth data. The Bureau of Chemistry and Soils, United States Department of Agriculture, cooperated in obtaining data concerning the soils of the county; and the department of agriculture, University of Minnesota, helped in obtaining the economic data. An attempt was made to present a picture of the financial results of man's effort in the use of land in the county. Some of the more important classes of the economic facts inventoried, and related to soil and cover types, concerned tax delinquency, mortgage indebtedness, assessment for taxation purposes, present use of land, type of land ownership, and expenditure of tax funds for schools, highways, etc.

A report of the results of the survey in this one county was not available in August, 1931. At that time it was the plan of the director of the survey to present the results on maps in so far as money necessary for that type of presentation was available.

New York State Land-Use Program

The State of New York has a comprehensive program to establish forests on lands not suited for agricultural use. This program was initiated by Chapter 195 of the Laws of 1929, popularly known as the senate reforestation act, which authorizes and directs the State conservation department to acquire, maintain, and reforest abandoned and idle farm lands throughout the State generally, except within the 16 so-called forest preserve counties in the Adirondack and Catskill Mountains. Chapter 194 of the Laws of 1929 known as the county reforestation act authorized the same activities on the part of counties and encouraged the counties to purchase land for reforestation purposes with the provision that the State would contribute on a dollar-for-dollar basis up to $5,000 to any one county in any one year for the purpose of purchasing and reforesting land unsuited for farming. Any plan submitted by the county authorities to take advantage of this State aid must receive the approval of the State commissioner of conservation.

The State reforestation act provided an appropriation of $120,000, $20,000 of which was to be used for forest-tree nursery purposes and the balance for purchase of land in units of 500 acres or more outside the forest-preserve counties.

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Recognizing the need for a more extensive program of reforestation than is provided in these two acts, a plan was developed which contemplates the acquisition and the reforesting by the State of 1,000,000 acres within a period of 15 years at a total cost of $20,000,000 as shown in Table 12 (*33, p. 88*).

TABLE 12.—*Program of acquisition and reforestation of land proposed by New York Reforestation Commission*

Year	Area to be acquired	Area to be reforested	Appropriation necessary	Year	Area to be acquired	Area to be reforested	Appropriation necessary
	Acres	*Acres*	*Dollars*		*Acres*	*Acres*	*Dollars*
1930	40,000	10,000	400,000	1939	100,000	90,000	2,000,000
1931	50,000	15,000	600,000	1940	100,000	100,000	2,000,000
1932	50,000	22,000	1,000,000	1941	100,000	100,000	2,000,000
1933	60,000	30,000	1,200,000	1942		100,000	2,000,000
1934	100,000	40,000	1,400,000	1943		100,000	
1935	100,000	50,000	1,600,000	1944		133,000	
1936	100,000	60,000	1,800,000				
1937	100,000	70,000	2,000,000	Total	1,000,000	1,000,000	20,000,000
1938	100,000	80,000	2,000,000				

To carry out the above program, a constitutional amendment was passed by the legislature and approved by the people at the fall election in 1931. The first part of this amendment provides that the legislature shall appropriate the money needed to complete the above program. The second part provides for the establishment of "production forests" in the forest-preserve counties outside the Adirondack and Catskill Parks. It provides

> that in the establishment and operation of these production forests, lands best suited for reforesting, which means bare, idle lands, in most cases abandoned farm lands, could be acquired by the State and planted to trees, and that forests so grown be utilized according to the best principles of forestry, not only for the production of timber and other forest products, but also for the protection of watersheds and other uses, such as recreation, which would be possible (*33, p. 87*).

This amendment was deemed necessary because the constitution prohibited, in section 7 of article 7 thereof, the cutting or utilization of any timber from an estimated 1,000,000 acres of idle, bare land now privately owned but located within the forest-preserve counties which the State might otherwise acquire. The amendment permits the purchase of this idle unwooded land with funds provided for therein and for cutting the timber, when it is mature, under the supervision of the State conservation department.

To insure completion of the program of land acquisition without additional cost, the conservation department has established $4 as the maximum per-acre price that may be paid. Although this price limitation may automatically limit the lands that the State could acquire to those unsuited for agricultural use, a program to classify lands in the State into five major classes is being carried out by the College of Agriculture of Cornell University, in cooperation with the State conservation department. The lands are divided into these five classes on the basis of their relative suitability for agriculture and forestry:

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Class I is adapted to forestry and not to farming. There is a large proportion of woodland in class I, and most of the land that was cleared for farms has been abandoned. Class I is ready for immediate purchase and reforestation by the State.

The land of Class II is better adapted to forests than to farming, but considerable farming is still done. Whenever it is possible for the State to purchase land in number II areas at a reforestation price, such land ought to be purchased and reforested.

Classes I and II make up our abandoned farm areas. There are occasionally idle farms in the other areas, but not large numbers of them.

Land class III is a mixed class. Some of the land is adapted to forests and some to farms. Some small public forests might be located in these areas, but no large ones.

Land class IV is primarily suited to agriculture. Most of the woodland in number IV areas will be found in farm woodlots.

Class V is adapted to a somewhat more intensive type of agriculture than number IV. Less woodland is found. More of the intensive crops are grown.[25]

This classification is made on the basis of an analysis of five main groups of factors—soils, topography and elevation, prosperity of people living on the land, farm-business records, and land cover.

A soil survey is made by the college of agriculture in cooperation with the United States Department of Agriculture. In addition to soil data, topography and elevation are considered to be important natural factors in determining in what class land belongs.

A third basis upon which to distinguish the five classes of land is the prosperity of the people who live in different areas. If many houses are vacant and falling, and if many of the occupied [houses] are tumbling down, we may conclude that the area is not good for farming. If the barns are usually small we know that the farmers never had many crops to store. If the woods seem to be creeping out into the edges of the fields and pastures, we know that the soil is not very valuable for farming. On the other hand, areas in which the fields are large and well kept, where the barns are large and in good repair, and where few farms are abandoned, are well adapted to agriculture. These factors can be measured quite reliably.

Records of farm-business operations obtained by the college of agriculture in connection with farm-management surveys over a long period of years furnish another valuable source of data for classifying land.

A fifth and very important aid in classifying the land is the cover map. In making a cover map, a base map is divided into uniform squares so that each square is equal to ten acres. The use of land for each ten acre square is recorded, whether woods, pasture, oats, potatoes, abandoned land, or some other kind of cover.

The areas of the different classes of land are located by means of presenting these types of data on base maps and correlating them in other ways. Briefly, the goal in this land-classification program is to designate the use of land which will best serve the individuals and the State. Among other desirable results the classification will furnish the basis for establishing equitable land tax and sound fiscal policies with respect to highway and school development. Besides furnishing the basis for public acquisition of a limited acreage of land unsuited for farming, it will provide fundamental data for establishing a sound directed land-settlement or agricultural-expansion program in all parts of the State.

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[25] LEWIS, A. B. LAND UTILIZATION. p. 3, 6. Cornell Univ. Col. Agr. 1929. [Mimeographed.]

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SUMMARY AND CONCLUSIONS

The existence of a very large area of land physically but not now economically suited for farming purposes; the enactment of laws which severely restrict immigration; a decided tendency that would indicate for our population a stationary stage at 140,000,000 to 150,000,000 at about 1960, provided immigration does not increase nor birth rates rise; the large-scale replacement of horses with tractors; the occurrence of remarkable changes in production technic and in consumption habits; and a precipitous drop in foreign demand for farm crops at a price that is profitable to producers, are a few of the important interrelated factors that have decidedly limited the economic need for increasing our net crop acreage.[26] Needless to say, these factors had a decidedly adverse influence on the working out of the type of State policies to promote the settlement of land that are discussed in this bulletin.

Efforts to establish profitable farms on land that is unsuitable for farming purposes or to develop and to settle lands in irrigation, drainage, and levee districts before demand justifies such development, result in an enormous waste of economic and human resources. Financially embarrassed and defunct drainage, levee, and irrigation enterprises in many parts of the country emphasize the need for public guidance of land settlement. Likewise, the financial embarrassment of counties, because large areas of land are reverting to public ownership through nonpayment of taxes, is resulting in a changed philosophy of settlement. Instead of the easy-going expansion philosophy of the past as a "cure all," the idea is developing in favor of directing future settlers to the best available lands adjoining developed communities, where schools, highways, and markets are already established and of discouraging attempts to develop reclamation projects that are not economically feasible.

FEDERAL POLICIES WITH RESPECT TO LAND SETTLEMENT

In general, Federal land-settlement policies in the past aimed at getting undeveloped land into farms. Little or no attention was given to the use for which land was best adapted. As long as large areas of good agricultural lands were available for sale or homestead entry, and a heavy demand for these lands existed, the evils of a haphazard program to dispose of these lands were not as evident as they are under present conditions.

The legislation that played so important a part in the disposition of the public domain has outlasted its usefulness. It is unlikely that in the future any large area will be taken up under existing homestead provisions; yet, if these laws are not repealed, uninformed persons doubtless will continue to enter land under the misapprehension that it will provide an adequate livelihood for a family.

STATE POLICIES WITH RESPECT TO LAND SETTLEMENT

The several States have adopted one or more land-settlement policies summarized briefly as follows:

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[26] BAKER, O. E. THE OUTLOOK FOR LAND UTILIZATION IN THE UNITED STATES. U. S. Dept. Agr. Ext. Ser. Circ. 168, 33 p., illus. 1931. [Mimeographed.]

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Policies to attract prospective settlers by use of advertisements and other publicity.

Policies to promote, finance, and administer the development of agricultural colonies and to develop and sell "ready-made farms" as demonstrations of the success the settler might expect.

Policies to aid and promote private settlement and colonization projects by certification of land-settlement and colonization company plans.

Policies to help finance the settler, usually with no special distinction between the requirements of settlers and those of more or less established farmers.

Policies to protect settlers against unscrupulous real-estate agencies through real estate licensing and blue sky laws, and by undertaking to make an inventory of land resources for the purpose of determining the use for which land is best adapted.

Until State agencies are prepared to direct prospective settlers to land physically and economically suited for farming purposes, the extravagant use of advertisements and other publicity media to attract them results in large economic and social loss. This means wasted capital, improper and uneconomic use of land resources, and especially incredible hardship, wasted time and labor, and consequent disappointment and discouragement of settlers.

Of the other methods of promoting land settlement, the method of State-operated colonies has had the greatest appeal for many people. It is the most picturesque of the several policies and makes interesting reading in magazine articles and in newspapers, but it has not proved to be a clearly desirable policy for a State to adopt. Successful experiments of this sort have been made in various parts of the world, but the record of failure, particularly in this country, has been extensive.

An important complex of reasons why government promoted colonies fail is political. Political considerations and influences have a tendency to prevent the impartial and impersonal exercise of business judgment in such matters as selection and purchase of land and materials, selection of settlers, credit policy, and general administration, and particularly in the collection of payments due from settlers. The experiences of the State administrative agencies charged with the duty of developing colonies since the World War furnish concrete examples of this overpowering influence. Even without this influence there are numerous opportunities for misjudgment in selecting land and in determining the best method for developing it, in setting up a sound financial plan, and in selecting settlers. Furthermore, the conditions of competition in agriculture are such that in the best of established farming areas a large proportion of the farmers fail to earn a moderate rate of interest on invested capital. Farm incomes fluctuate widely from year to year. Yet the State and other agencies that attempt to establish colonies usually overlook or discount the importance of considering such data as are available concerning the national and international demand for crops. Similarly, the comparative advantages of producing crops in different sections of the country usually are not given adequate consideration. But capital costs for improving farms, selecting settlers, etc., become due regardless of how good or bad the market is for crops grown on the project.

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Farm and community improvements in advance of settlement remove many of the obstacles the settlers might otherwise have to overcome. The paternalistic policy on which such improvements are based, however, is costly from the beginning. The type of settler who is most likely to be attracted by such a policy may not be willing to undergo hardships during periods of stress. He will usually appeal for more help from the colonizing agencies as difficulties arise. The resultant complex of these conditions has proved to be a major cause for failure of State promoted and operated colonization projects in this country.

The goal of the policy to certify land-settlement projects is to give the State's seal of approval only to those enterprises which represent the highest standard of efficiency and desirability from the standpoint of the settler. But if certification is optional and involves payment by the concern for expenses of investigation, there is a tendency for only those firms which are consciously superior in methods and opportunities to apply for this official approval. The less desirable companies continue to operate outside of the system. That is what has happened under the law in Michigan. A compulsory land certification law similar to the Michigan law in other respects possibly could be made the basis for preventing settlement on land unsuitable for farming purposes.

State certification of the bonds of any land settlement or development company enables the State to promote, and in certain respects to regulate, the development of land. If a minimum requirement for certification provides that proposed projects be both economically feasible and socially desirable, such a policy is highly commendable. On the other hand, if bonds are certified before adequate study had been made to determine whether the proposed project is economically sound and socially desirable, State certification of bonds may result in the development of projects that are doomed to failure from the start.

A source of the right kind and amount of credit at a nominal cost is basic for success of the average settler in developing prosperous farming enterprises from raw land. The establishment of State rural-credit agencies by the various States is an attempt to meet this need as well as the farm-mortgage credit needs of established farmers. This dual-purpose policy has not proved to be entirely successful. Credit needs in an undeveloped area are not the same as those in a developed area. The usual credit terms in most newly developing areas are frequently unsuited to local conditions. If they are liberal, the settler is compelled to pay for them in high land prices.

The settler needs loans on a long-time amortization basis, but he requires somewhat more credit than he can obtain under the provisions of the Federal farm loan system. Moreover, the agencies of this system are properly cautious about extending their lending activities into the undeveloped districts. The settler should be able to obtain, not a single large loan on which he begins at once to pay interest, but something similar to a line of credit which will become available gradually as made necessary by the requirements of farm development. In some cases it is desirable that interest payments

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or at least amortization payments be postponed from one to three years.

Unduly "easy" terms of credit are not always desirable. They are likely to attract would-be settlers who have never succeeded in accumulating much property and who are lacking in farming experience or business ability. In fact, the tendency to enable men to acquire farms with little or no capital is a result of the forcing process of land settlement which is the outgrowth of public (especially local) impatience at normal rates of expansion. Many private holders of land are forced to place their holdings on the market because of taxes and other carrying charges.

If the artificial stimuli to expansion of our farm area could be removed and agriculture be allowed to expand under the normal stimulus afforded by a reasonable expectation of profitable operation in new areas, it is probable that a class of substantial farm investors would develop. In this case settlers would not need the coddling of excessive credit and administrative supervision of State agencies. They would need protection against fraud and misrepresentation on the part of land-selling agencies and such technical assistance as would enable them to avoid costly mistakes in the selection of projects and in making adjustments to new conditions. It would seem that it should be a public function to provide such services.

Uniform real estate license and blue sky laws in each State, together with the existing postal laws, could possibly be made to serve as substantial regulatory measures, provided they are administered in the light of facts necessary to formulate sound land-settlement policies as part of coordinated Federal and State land-use planning programs. Under existing conditions, these regulatory laws are made effective only in regard to the conspicuously fraudulent practices of the land-selling agencies when brought to the attention of the administrators of the laws. The development of a more positive and constructive policy of aiding settlers in finding the best opportunities and in avoiding costly mistakes would probably necessitate the setting up of a rural planning commission or a land utilization commission in each State, authorized and directed to cooperate with a corresponding Federal agency: (1) In coordinating the activities of regulatory and other public offices which in one way or another affect the use of land, and (2) in developing sound land-settlement policies as part of the land-use planning programs.

The development of sound land-use planning programs calls for a thorough survey of physical, economic, social, fiscal, and other conditions. Of equal importance is an analysis of all these factors and conditions in the light of regional, national, and even international tendencies and policies which directly or indirectly influence the use of land. The complete development of a planning program in any area or region could be developed most effectively by coordinated efforts of local, State, and Federal agencies. The soil, geological, weather, and such other data made available by the Federal Government, as influence the use of land, are indispensable basic factors in the determination of the use for which land is best adapted. Likewise, the land-inventory and classification work of the various

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States, particularly Michigan, Wisconsin, Minnesota, and New York provides much essential physical and economic data.

Neither the one agency nor the other, alone, can effectively develop an adequate policy. The States have much more adequate constitutional powers for dealing directly with various problems connected with private property in land than has the Federal Government. They are closer to local conditions and frequently more capable of dealing effectively with the varied circumstances existing in different localities.

But although local and State governments can go far in initiating certain lines of investigation they are seriously handicapped in the solution of the major problems involved. The necessary finances and investigational technic and facilities are beyond the resources of many States and particularly of those States in which the land-use problems are in greatest need of solution. Moreover, the regional aspects, which are usually interstate in character, and the national outlook with respect to comparative advantages for the production of specific farm and forest crops, are important phases of what may appear to be local problems. The States or local units of government can not afford to develop either these regional aspects or the national outlook information, nor can they afford not to take them into consideration.

The Federal Government is equipped to do much of this work. Through its many interests in the development of sound land policy as one of the fundamental necessities of long-time farm relief, the various research and extension resources of the United States Department of Agriculture, and possibly other Federal agencies might take an important part in the necessary investigational program and in formulating lines of essential action by public and private agencies.

Furthermore, the Federal Government still controls a public domain of vast extent, including the national forests and national parks. It legislates with reference to immigration, and is in a stronger position than the individual States for dealing with the various problems arising from interstate migration and interstate sale of land. Through the tariff policy and through control of railway rates, it may exert an important influence on the margins of agricultural development, both national and local. Through its road-building program, its improvement of navigable waters, and its already developed reclamation policies it can determine to some extent the direction of development. Furthermore, the Federal Government is in a position to view the land problem from the broader outlook of the Nation as a whole, whereas the States tend to reflect the influence of local interests, which may seek an undue development with little thought of consequences to other localities.

Through the research and extension facilities of the United States Department of Agriculture and other Federal agencies, the Federal Government, jointly with the States, may exert an important educational influence. Facts made available in the development of land-use planning programs would furnish the basis for disseminating sound advice to prospective settlers, land-selling agencies, various business interests, and legislators and other public agencies concerned with the farmers' welfare. Through coordinated efforts on

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the part of State and Federal interests a publicity and service agency might be organized to prevent the loss of economic and human resources resulting from attempts to establish farms in areas not suitable for farming. A publicity and service bureau of this kind could help land-selling companies develop sound programs to expand the agricultural area when economically feasible and socially desirable. Cooperation with industries and industrial centers in ascertaining the feasibility of promoting the development of part-time farming opportunities could be another of its functions. It might also serve to coordinate the activities of various State agencies interested in land settlement and help to direct agricultural expansion to those areas in which the chances for success appear to be greatest.

LITERATURE CITED

(1) AMERICAN BAR ASSOCIATION.
1929. UNIFORM SALE OF SECURITIES ACT DRAFTED BY THE NATIONAL CONFERENCE OF COMMISSIONERS ON UNIFORM STATE LAWS . . . Amer. Bar. Assoc. Ann. Conf. 39, 35 p.

(2) ARIZONA [LAWS, STATUTES, ETC.]
1921. THE ARIZONA LAND SETTLEMENT ACT. Ariz. Session Laws 1921, ch. 58, p. 106–113.

(3) BAKER, O. E.
1931. A GRAPHIC SUMMARY OF AMERICAN AGRICULTURE BASED LARGELY ON THE CENSUS. U. S. Dept. Agr. Misc. Pub. 105, 228 p., illus.

(4) BLACK, J. D., and GRAY, L. C.
1925. LAND SETTLEMENT AND COLONIZATION IN THE GREAT LAKES STATES. U. S. Dept. Agr. Dept. Bul. 1295, 88 p., illus.

(5) BOGGS, HOLLISTER, HARRIS, BROCK, CLOUDMAN, and ANDERSON, R. J.
1925. REPORT OF SPECIAL COMMITTEE. Calif. Legislature Assembly Daily Jour. March 17, 1925, p. 4–6.

(6) BOYD, G. R., and HART, R. A.
1924. DRAINAGE DISTRICT ASSESSMENTS; A STUDY OF PRESENT PRACTICES IN ASSESSING BENEFITS UNDER THE STATE DRAINAGE LAWS. U. S. Dept. Agr. Bul. 1207, 70 p.

(7) CHRISTOPHERSON, F. C.
1929. A STATE GOES INTO BUSINESS—AND OUT AGAIN. Nation's Business 17(5): 48–50, 177, 178, illus.

(8) CLEARY, C. W.
1928. DIVISION OF LAND SETTLEMENT. Calif. Dept. Agr. Mo. Bul. (1927) 16: 748–758.

(9) ———
1931. STATE LAND SETTLEMENT. Calif. Dept. Agr. Mo. Bul. 20: 322–324.

(10) DAVIS, G. W. H., and KARNEY, C. W.
1925. SPECIAL REPORT ON SOLDIER LAND SETTLEMENT PROJECT, WHITE BLUFFS AND HANFORD, WASHINGTON, MARCH 31, 1925. *In* Washington Department of Conservation and Development, Special Report on Reclamation Revolving Fund, Land Settlement, Whitestone Reclamation District, Kittitas Project, and Columbia Basin Project, to Legislature in Special Session, p. 1–88. Olympia.

(11) DUFFY, W. A., WHITSON, A. R., and WEHRWEIN, G. S.
1929. THE LAND ECONOMIC INVENTORY OF NORTHERN WISCONSIN; WHAT IT IS AND WHAT IT CAN BE USED FOR. Wis. Dept. Agr. Bul. 97, 15 p., illus.

(12) ——— and others.
1929. LAND ECONOMIC INVENTORY OF NORTHERN WISCONSIN, BAYFIELD COUNTY. Wis. Dept. Agr. Bul. 100, 93 p., illus. [In three parts, each part by different authors.]

(13) GALPIN, C. J.
1931. FARM POPULATION STARTS GAINING. U. S. Dept. Agr., Bur. Agr. Econ. Agr. Situation 15(3): 2–4.

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(14) GRAY, L. C., and BAKER, O. E.
1930. LAND UTILIZATION AND THE FARM PROBLEM. U. S. Dept. Agr. Misc. Pub. 97, 54 p., illus.

(15) ——— BAKER, O. E., MARSCHNER, F. J., WEITZ, B. O., CHAPLINE, W. R., SHEPARD, W., and others.
1924. THE UTILIZATION OF OUR LANDS FOR CROPS, PASTURE, AND FORESTS. U. S. Dept. Agr. Yearbook 1923: 415–506, illus.

(16) HARTMAN, W. A., and BLACK, J. D.
1931. ECONOMIC ASPECTS OF LAND SETTLEMENT IN THE CUT-OVER REGIONS OF THE GREAT LAKES STATES. U. S. Dept. Agr. Circ. 160, 86 p., illus.

(17) HIBBARD, B. H., HARTMAN, W. A., and SPARHAWK, W. N.
1929. USE AND TAXATION OF LAND IN LINCOLN COUNTY, WISCONSIN. Wis. Agr. Expt. Sta. Bul. 406, 38 p., illus.

(18) ———SWENEHART, J., HARTMAN, W. A., and ALLIN, B. W.
1928. TAX DELINQUENCY IN NORTHERN WISCONSIN. Wis. Agr. Expt. Sta. Bul. 399, 28 p., illus.

(19) HUTCHINS, W. A.
1929. FINANCIAL SETTLEMENTS OF DEFAULTING IRRIGATION ENTERPRISES. U. S. Dept. Agr. Circ. 72, 46 p.

(20) ———
1931. IRRIGATION DISTRICTS, THEIR ORGANIZATION, OPERATION, AND FINANCING. U. S. Dept. Agr. Tech. Bul. 254, 94 p., illus.

(21) ———
1931. SUMMARY OF IRRIGATION-DISTRICT STATUTES OF WESTERN STATES. U. S. Dept. Agr. Misc. Pub. 103, 127 p.

(22) KARNEY, C. W.
1927. WHITE BLUFFS—HANFORD STATE LAND SETTLEMENT PROJECT. Wash. Dept. Conserv. and Devlpmnt. Bien. Rpt. (1925/26) 3: 68–70.

(23) KNIGHT, H. G.
1931. REPORT OF THE CHIEF OF THE BUREAU OF CHEMISTRY AND SOILS. U. S. Dept. Agr., Bur. Chem. Ann. Rpt., 78. p.

(24) MACCHESNEY, N. W.
1927. MACCHESNEY ACT FOR A STATE REAL ESTATE LICENSE LAW. Natl. Assoc. Real Estate Bds., 21 p. Chicago.

(25) MARSDEN, R. D., and TEELE, R. P.
1930. ECONOMIC STATUS OF DRAINAGE DISTRICTS IN THE SOUTH IN 1926. U. S. Dept. Agr. Tech. Bul. 194, 48 p.

(26) MEAD, E.
1929. A NATIONAL RECLAMATION POLICY; ECONOMIC ASPECTS OF FEDERAL RECLAMATION. Amer. Soc. Civil Engin. Proc. 55: [1207]–1213.

(27) ———
1931. THIRTIETH ANNUAL REPORT OF THE COMMISSIONER OF RECLAMATION . . . FOR THE FISCAL YEAR ENDED JUNE 30, 1931. 120 p. [[U. S.] Congress 72d, 1st Sess., House Doc. 29.]

(28) MENDENHALL, W. C.
1931. ANNUAL REPORT OF THE DIRECTOR OF THE GEOLOGICAL SURVEY. U. S. Geol. Survey Ann. Rpt. 52, 95 p.

(29) MICHIGAN [LAWS, STATUTES, etc.]
1923. AN ACT TO PROVIDE FOR CERTIFICATION OF THE UNIMPROVED LAND AND IMPROVED FARMS IN THE STATE OF MICHIGAN . . . Mich. Pub. Acts 1923, p. 463–466. (Act. 292.)

(30) MINNESOTA [LAWS, STATUTES, etc.]
1929. SESSION LAWS OF THE STATE OF MINNESOTA . . . AUTHORIZING AND DIRECTING THE DEPARTMENT OF CONSERVATION TO MAKE A LAND ECONOMIC SURVEY OF ALL LAND IN THE STATE OF MINNESOTA AND APPROPRIATING MONEY THEREFOR. Minn. Statutes 1929, ch. 247, S. F. 47, p. 275–276.

(31) MISSOURI LAWS.
1923. AN ACT RELATING TO THE SALE OR OTHER DISPOSAL OF SECURITIES AND PROVIDING PENALTIES FOR THE VIOLATION THEREOF AND TO REPEAL ACTS IN CONFLICT HEREWITH, WITH AN EMERGENCY CLAUSE. Missouri Laws, H. B. 236, p. 200–218.

(32) MOORE, C. C.
1931. ANNUAL REPORT OF THE COMMISSIONER OF THE GENERAL LAND OFFICE TO THE SECRETARY OF THE INTERIOR, FOR FISCAL YEAR ENDED JUNE 30, 1931. 76 p.

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(33) New York Conservation Department.
1930. TWENTIETH ANNUAL REPORT FOR THE YEAR 1930. 476 p., illus. Albany. (Legis. Doc. (1931) no. 38).
(34) Schoenmann, L. R.
1929–30. LAND ECONOMIC SURVEY DIVISION. Mich. Dept. Conserv. Bien. Rpt. 5: 73–90, illus.
(35) Spry, W.
1924. SUGGESTIONS TO HOMESTEADERS AND PERSONS DESIRING TO MAKE HOMESTEAD ENTRIES. U. S. Dept. Int., Gen. Land Off. Circ. 541, 52 p.
(36) Teele, R. P.
1924. LAND RECLAMATION POLICIES IN THE UNITED STATES. U. S. Dept. Agr. Bul. 1257, 40 p., illus. (Rev. January, 1927.)
(37) United States Congress.
1930. LOANS FOR RELIEF OF DRAINAGE DISTRICTS. (Report to accompany S. 4123.) 11 p. [U. S. Cong. 71st, 3d Sess., H. R. 2169.]
(38) United States Department of Commerce, Bureau of the Census.
1920–1930. UNITED STATES CENSUS OF AGRICULTURE. U. S. Bur. of the Census 1920 and 1930.
(39) ———
1930. OCCUPATION STATISTICS. U. S. Bur. of the Census, U. S. Summary 1930.
(40) United States Department of the Interior, General Land Office.
1930. VACANT PUBLIC LANDS ON JULY 1, 1930. U. S. Dept. Int., Gen. Land Off. Circ. 1230, 15 p.
(41) ——— Office of Indian Affairs.
1930. GENERAL DATA CONCERNING INDIAN RESERVATIONS (REVISED TO JUNE 30, 1929). 21 p.
(42) United States Department of Labor, Bureau of Immigration.
1910–31. ANNUAL REPORT OF THE COMMISSIONER GENERAL OF IMMIGRATION TO THE SECRETARY OF LABOR . . . 1910–1931.
(43) United States Laws, Statutes, etc.
1925. AN ACT MAKING APPROPRIATIONS TO SUPPLY DEFICIENCIES IN CERTAIN APPROPRIATIONS FOR THE FISCAL YEAR ENDED JUNE 30, 1924, AND PRIOR FISCAL YEARS, TO PROVIDE SUPPLEMENTAL APPROPRIATIONS FOR THE FISCAL YEAR ENDED JUNE 30, 1925, AND FOR OTHER PURPOSES. *In* U. S. Statutes at Large, v. 43, pt. 1, p. 672–704. (U. S. Congress 68th, 2d Sess., Public 292, 1924.)
(44) Wisconsin Laws, Statutes, etc.
1929. AGRICULTURE; FOODS AND DRUGS; MARKETS. Wis. Statutes 1929 . . . Title 12, ch. 93, Subsection 10, p. 1116.
(45) Yohe, H. S.
1917. ORGANIZATION, FINANCING, AND ADMINISTRATION OF DRAINAGE DISTRICTS. U. S. Dept. Agr. Farmers' Bul. 815, 37 p.

APPENDIX

LIST OF AGENCIES HAVING STATE LANDS FOR SALE OR LEASE

Alabama, State Commission of Forestry, 500 Dexter Avenue, Montgomery.
Arizona, State Land Commissioner, Phoenix.
Arkansas, Commissioner of State Lands, Little Rock.
California, Department of Finance, Division of State Lands, Sacramento.
Colorado, State Board of Land Commissioners, Denver.
Florida, Commissioner of Agriculture, Tallahassee.
Idaho, State Board of Land Commissioners, Boise.
Louisiana, Commissioner of State Lands, Baton Rouge.
Michigan, Lands Division, Department of Conservation, Lansing.
Minnesota, State Auditor, State Capitol, St. Paul.
Mississippi, Commissioner of State Lands, Jackson.
Montana, State Board of Land Commissioners, Helena.
Nebraska, Commissioner of Public Lands and Buildings, Lincoln.
Nevada, Surveyor-General, Department of State Lands, Carson City.
New Mexico, Commissioner of State Lands, Santa Fe.
North Carolina, Superintendent of Public Instruction, Raleigh.

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North Dakota, Commissioner of State Lands, Bismarck.
Oklahoma, Commissioner of State Lands, Oklahoma City.
Oregon, State Land Board, Salem.
South Dakota, Commissioner of School and Public Lands, Pierre.
Texas, Land Department, University of Texas, Magnolia Building, Dallas.
Utah, State Land Office, Salt Lake City.
Washington, Commissioner of Public Lands, Olympia.
Wisconsin, Commissioner of Public Lands, Madison.
Wyoming, Commissioner of Public Lands, Cheyenne.

STATE AGENCIES AUTHORIZED BY LAW TO COLLECT, COMPILE, AND DISSEMINATE INFORMATION TO ATTRACT CAPITAL AND SETTLERS

Alabama, Commissioner of Agriculture and Industries, Montgomery.
Arkansas, Department of Agriculture, Bureau of Crop Estimates and Immigration, Little Rock.
Colorado, State Board of Immigration, Denver.
Florida, Commissioner of Agriculture, Tallahassee.
Georgia, Commissioner of Agriculture, State Capitol, Atlanta.
Illinois, Director of Agriculture, Springfield.
Louisiana, Commissioner, State Board of Agriculture and Immigration, New Orleans.
Massachusetts, Commissioner, Department of Agriculture, State House, Boston.
Michigan, State Conservation Commission, Lansing.
Mississippi, Commissioner, Department of Agriculture, Jackson.
Missouri, Commissioner, Department of Agriculture, Jefferson City.
New Hampshire, Commissioner, Department of Agriculture, Concord.
New York, Commissioner, Department of Agriculture and Markets, Albany.
North Carolina, Director, Department of Conservation and Development, Raleigh.
North Dakota, Commissioner of Immigration, Bismarck.
South Carolina, Commissioner, Department of Agriculture, Commerce, and Industries, Columbia.
South Dakota, Department of Agriculture, Pierre.
Tennessee, Department of Agriculture, Division of Markets, Nashville.
Utah, Commissioner, Bureau of Immigration, Salt Lake City.
Virginia, Commissioner of Agriculture and Immigration, Richmond.
Washington, Secretary of State, Olympia.
West Virginia, Commissioner, Department of Agriculture, Charleston.
Wisconsin, Commissioner, Department of Agriculture and Markets, Madison.
Wyoming, Department of Commerce and Industry, Capitol Building, Cheyenne.

NOTE.—State agencies in Kentucky, Maine, Minnesota, Nebraska, New Hampshire, Pennsylvania, and Vermont publish various types of pamphlets describing resources, but no special law has been enacted directing any particular State agency to collect, compile, and disseminate information to attract capital and settlers.

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LABORATORY AND FIELD TESTS OF CONCRETE EXPOSED TO THE ACTION OF SULPHATE WATERS

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TECHNICAL BULLETIN No. 358 JUNE 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

LABORATORY AND FIELD TESTS OF CONCRETE EXPOSED TO THE ACTION OF SULPHATE WATERS [1]

By DALTON G. MILLER, *Senior Drainage Engineer, Division of Drainage and Soil Erosion Control, Bureau of Agricultural Engineering, United States Department of Agriculture,* and PHILIP W. MANSON, *Division of Agricultural Engineering, Agricultural Experiment Station, University of Minnesota* and *Division of Drainage and Waters, Minnesota State Department of Conservation*

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INTRODUCTION

In the spring of 1919 the attention of the United States Department of Agriculture was called to a number of failures of concrete tile in the ground in southwestern Minnesota. At a conference between various interested organizations the Bureau of Public Roads [2] agreed to inves-

[1] A report of progress of experiments conducted under cooperative agreement between the Bureau of Agricultural Engineering of the U. S. Department of Agriculture, the University of Minnesota, and the Division of Drainage and Waters of the Department of Conservation, State of Minnesota. In the files of the university this report is Journal Series Paper No. 1106 of the Agricultural Experiment Station.

[2] Prior to the organization of the Bureau of Agricultural Engineering in 1931, the work of the U. S. Department of Agriculture in this investigation was done by the Division of Agricultural Engineering of the Bureau of Public Roads.

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tigate the situation. A systematic field study was begun in the fall of 1919 and covered 23 counties in Minnesota and 4 counties in northern Iowa. Tile failures were located and samples of drain water and soil water analyzed. The study revealed a marked correlation between alkali [3] concentrations and failures of concrete tile. A laboratory was established at University Farm, St. Paul, Minn., in cooperation with the Agricultural Experiment Station and the Department of drainage and waters [4] of the State, to make an exhaustive investigation of the effect of alkali waters on concrete.

The act of the 1920 session of the Minnesota Legislature that provided funds for the draintile laboratory called for an "investigation of the causes of failure of agricultural draintile, the means of obviating such failures, and mapping of areas where extra precautions are necessary." In July, 1921, a bulletin (*57*)[5] based on many field examinations of draintile and on chemical analyses of 1,062 water samples and 150 soil samples, clearly showed the cause of failure to be the presence of alkali in the subsoil, in the form of the sulphates of magnesium ($MgSO_4$) and sodium (Na_2SO_4). In January, 1927, a bulletin (*35*) was published containing a map of Minnesota showing where extra precautions in using concrete tile had been found necessary.

This bulletin is intended to furnish to engineers, tile manufacturers, and tile users, additional information that will more nearly make it possible to completely obviate failures of agricultural draintile. At the same time the bulletin will make generally available the results of the work to date. It gives results of observations on the behavior of experimental specimens subjected to the action of artificial sulphate solutions in the laboratory, and the behavior of specimens installed under natural-field exposure conditions in Minnesota, North Dakota, and South Dakota. For this work more than fifty thousand 2 by 4 inch cement-concrete and cement-mortar cylinders, 1,000 cement-mortar briquets, 3,000 specially made concrete draintile, and numerous miscellaneous specimens, have been made. The experiments, while originally planned to aid in the general improvement of farm draintile, have a wide application to the use of concrete culverts, water and sewer pipe, irrigation structures, foundations, and all other types of concrete construction that, in service, must resist the action of soils or waters rich in sulphates.

EARLY STUDIES OF THE CONCRETE-ALKALI PROBLEM

Since the invention of Portland cement in 1824 many studies have been made and much research is still under way, looking toward solving the problem of deterioration of cement in contact with sulphate waters. It is believed that the following brief historical review will be helpful to workers in this field.

Among the many earlier European workers on this subject are Le Chatelier (*30*), in 1887, Michaelis (*32*) in 1891, and Feret (*22*, in 1890. Bied (*10*) in 1909 reported the results of 6 years laboratory tests of the action of sulphate solutions on mortars containing artificial pozzuolanas. Poulsen in 1923 issued a report (*43*) in which he

[3] The word "alkali" is used throughout this bulletin in the sense in which it is commonly used in arid and semiarid regions of the United States, and may mean any one or more, singly or in combination, of the sulphates, chlorides, and carbonates of sodium, magnesium, and calcium. In this sense sea water can be classed as "alkali" water.

[4] Now the Division of Drainage and Waters of the Department of Conservation.

[5] Italic numbers in parentheses refer to Literature Cited, p. 77.

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describes a series of field experiments started on a comprehensive scale in 1896 by the Scandinavian Association of Manufacturers of Portland Cement, to determine the influence of various factors on the resistance of concrete exposed to sea water; Candlot (*16*) reviewed the results and conclusions by Viennot and other French engineers based largely on 40 years of investigations of experimental cubes installed between 1856 and 1875 in the harbor of LaRochelle. French engineers and chemists acknowledged the existence of the "alkali" problem three-quarters of a century ago. In fact, studies by both the French and English are older than Portland cement, for Vicat recognized the problem as far back as 1812 in connection with work on limes and natural cements reported upon in 1818 (*50*). Antedating the work of Vicat by more than a half century, Smeaton (*44*) experimented to secure a mortar that would best resist sea water, when he built the Eddystone Lighthouse in 1756–1759.

The concrete-alkali problem was not seriously considered in North America until nearly the beginning of the present century, after failures of important structures in widely separated parts of the country had occurred. Very evident deterioration of maritime structures along the North Atlantic seaboard, particularly in Boston Harbor, finally focused the attention of engineers and chemists of the eastern United States and resulted in an impressive series of field tests by the Aberthaw Construction Co. of Boston (*2*). This company, in 1909, made 24 concrete beams 16 feet long by 16 inches square and suspended them in Boston Harbor, in Charlestown Navy Yard, with their tops above high water and their bottoms below low water, so that they were subjected to the chemical action of sea water, to the mechanical effect of alternate wetting and drying, and to frost.

More or less contemporaneous with the Aberthaw tests, but entirely independent and possibly antedating them in some phases, were studies by the United States Bureau of Standards reported by Bates, Phillips, and Wig (*8*) in 1912. That paper was based on observations and chemical examinations of hollow test cylinders 3½ inches in outside diameter and 10 inches long through which were passed solutions of various kinds, and on compression tests of 8 by 16 inch cylinders installed in the open sea. These studies were fundamental in nature, and the behavior of mortar and concrete specimens of Portland, slag, iron-ore, and natural cements was observed.

About the time the Aberthaw tests in Boston Harbor were begun the interest of engineers and chemists throughout the western United States was aroused by disintegration of sections of the sewer system of Great Falls, Mont., as reported upon by Tannatt and Burke (*47*) in 1908. The first failure noted in this sewer system occurred in a 26 by 32 inch oval main shortly after its construction in 1890. This failure occurred about the time that extensive reclamation development began in the West. Troubles that developed with concrete structures built by the United States Reclamation Service in alkali soils and waters were reported by Jewett in 1908 (*27*). Also in 1908 was issued the pamphlet by Headden (*25*) based chiefly on limited chemical work that followed observed failures of small draintile in western Colorado. In 1910 a bulletin by Burke and Pinckney (*14*), containing chemical analyses and observed physical effects of storing briquettes in sulphate, carbonate, chloride, and other solutions, was

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published. In 1915 the paper by Wig and Williams (*54*) based on results of the first year's tests of experimental tile installed in alkali soils in eight Western States was issued. Other reports on this work followed in 1917 (*55*), 1922 (*58*), and 1926 (*59*). Along the same general line as the paper by Burke and Pinckney in 1910, but broader, was the bulletin by Steik (*46*) published in 1917 and based on extended tests of briquettes in many solutions of several strengths for periods of as much as seven years.

A great many other papers reporting investigations and research on deterioration of concrete exposed to alkali have been printed since the inception of the Aberthaw tests and the report of the failure of the Great Falls sewer, coming from many sources in North America. Among them the following three are considered particularly noteworthy because of their historical and bibliographic matter: (1) A bibliography of the United States Department of Agriculture issued in 1925 (*28*) and supplemented in 1931[6] is the most complete compilation of references on this subject. (2) Atwood and Johnson (*6*), trace the history of cement in sea water and analyze results obtained by various investigators. This paper cites 113 references. (3) A paper by Pagon (*40*), first published in 1915-16 is a comprehensive collection of the experiences and opinions of many workers, and has appended references to 145 printed articles.

ORGANIZATIONS MAKING CONCRETE-ALKALI INVESTIGATIONS

Although valuable reports on various phases of concrete-alkali investigations emanated from many sources between 1920 and 1930, there developed during this period an evident tendency in the United States and Canada to leave such work to organizations sufficiently interested properly to finance research that was broader and more fundamental in scope, for the most part, than much of the research previously undertaken. Some such organizations, now active, are:

The Bureau of Standards of the United States Department of Commerce makes investigations on the effect of alkali on Portland cement in cooperation with the Portland Cement Association, through a fellowship created in 1924 for fundamental studies of the constitution and hardening of Portland cement.

The research laboratory of the Portland Cement Association began in 1921 a comprehensive series of field and laboratory tests of Portland cement specimens exposed to alkali. In addition to doing the laboratory work, this organization has periodically examined some 2,000 concrete cylinders 10 inches in diameter and 24 inches long, after their exposure to sulphate soils and waters in Colorado, South Dakota, and western Canada.

The Engineering Institute of Canada in 1921 appointed a committee on deterioration of concrete in alkali soils, to continue the concrete-alkali investigations begun in 1918 by the Calgary branch of the institute and in 1919 by the University of Saskatchewan as field experiments carried on by exposing concrete blocks of known quality to sulphate waters. Between 1921 and 1928 the work was financed by the National Research Council of Canada, the Canadian Pacific Rail-

[6] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF AGRICULTURAL ENGINEERING. SUPPLEMENTARY BIBLIOGRAPHY RELATING TO THE DELETERIOUS ACTION OF SOIL ALKALIES AND OTHER CHEMICAL AGENTS ON CEMENT AND CONCRETE. 15 p. 1931. [Mimeographed.]

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way, the Canada Cement Co., the city of Winnepeg, the three prairie Provinces, and the University of Saskatchewan, but in 1928 the National Research Council of Canada took this over and it is now carried on almost exclusively in the chemical laboratory of the University of Saskatchewan.

The Bureau of Public Roads has been conducting experiments with mortar and concrete cylinders surface treated or immersed in such preparations as water-gas tar, coal tar, and paraffin. In this work the physical effects of alkali action have been studied chemically and microscopically.

GENERAL DESCRIPTION OF TESTS

TEST SPECIMENS

Most of the test specimens were cylinders 2 inches in diameter by 4 inches long, used partly because the 2-inch diameter roughly approximates the wall thickness of many of the tile used in public drains in Minnesota and other States of the Middle West. A small number of standard briquets and commercial draintile were also tested.

The greater number of the test cylinders were made of concrete, not merely mortar, although only pebbles small enough to pass a ⅜-inch square opening were used. The aggregate met all standard physical tests. It was separated into screen sizes and recombined, as shown in Table 1, to produce a fineness modulus of 4.67. The mineralogical composition of a sample of the combined materials is recorded in Table 2. Roughly, about 75 per cent of the aggregate may be classed as siliceous, 15 per cent argillaceous, and 10 per cent calcareous. The unit dry weight of the combined fine and coarse aggregate was 124 pounds per cubic foot. This was the highest unit weight of dry-rodded material that could be obtained by any combination of screen sizes, as was determined by repeated trials. The average weight of the concrete cylinders 24 hours after they were made, was about 505 grams and variations of individual cylinders from this average rarely exceeded 2 per cent.

TABLE 1.—*Screen analysis of aggregate and quantity of each size used for 9-cylinder batch of 2 by 4 inch laboratory standard cylinders*

Screen size	Passing screen	Retained on screen	Total coarser than screen	Required for batch
	Per cent	*Per cent*	*Per cent*	*Grams*
⅜-inch	100.0	0	0	----------
No. 4	56.3	43.7	43.7	1,543
No. 8	36.3	20.0	63.7	706
No. 16	24.4	11.9	75.6	420
No. 30	12.5	11.9	87.5	420
No. 50	3.1	9.4	96.9	332
No. 100	.4	2.7	99.6	110
Total	----------	----------	467.0	3,531
Fineness modulus	----------	----------	4.67	----------

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TABLE 2.—*Petrological count of aggregate used in laboratory standard cylinders*

Component	Portion of entire sample	Portion of screen size			
		Passing ⅜-inch; retained on No. 4	Passing No. 4; retained on No. 10	Passing No. 10; retained on No. 20	Passing No. 20
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sandstone	27.6	33.0	30.0	22.0	10.0
Quartz	15.4	3.0	4.0	33.5	63.0
Slate	13.0	12.5	18.0	10.8	4.0
Granite	11.9	15.0	15.5	6.2	1.0
Rhyolite	10.8	12.5	13.0	7.0	5.0
Limestone	9.8	12.0	11.5	5.3	4.0
Chert	4.4	7.0	4.0	1.7	1.0
Feldspar	4.2	----------	1.0	13.5	12.0
Gneiss	2.9	5.0	3.0	----------	----------
Total	100.0	100.0	100.0	100.0	100.0

E. C. E. Lord, Bureau of Public Roads, U. S. Department of Agriculture.

The cylinders with some exceptions were made in batches of nine. Each series consisted of five batches made on different days of the same week, the order of making being changed daily so that for the week it was the same for all series. Most of the cylinders were of 1:3 mix, with a relative consistency of 1.00 and a water-cement ratio of 0.62, which is 4.6 gallons of water per bag of cement. Each batch was mixed by hand at least 1½ minutes dry and 2 minutes after the water was added. After being mixed the materials were rodded in four layers in three 3-gang brass molds, each layer being tamped 20 times with a round-pointed steel rod ⅜ by 15 inches in size. The cylinders were cured during the first 24 hours in a moist closet at room temperature. Following this routine, using local sand and gravel and storing the cylinders in distilled water until tested, produced concrete with high compressive strengths, generally in excess of 4,500 pounds at 28 days, and with an absorption of 6 per cent when tested in accordance with the American Society for Testing Materials standard specifications for draintile (*5*), which provide for oven drying at a temperature of not less than 230° F. followed by 5 hours in boiling water.

A limited number of mortar cylinders and standard briquets were made of standard Ottawa sand, and these fairly well represented very poorly graded aggregate characteristic of that used too frequently in small draintile. The compressive strength of the mortar cylinders that were mixed 1:3 ordinarily averaged between 2,500 and 3,000 pounds per square inch at 28 days, with an absorption of 10 per cent when the cylinders were tested like the others. Draintile of 5 and 6 inches diameter were made at three commercial tile plants.

EXPOSURE CONDITIONS

It was originally planned to base most of the conclusions on results obtained with cylinders stored in solutions in the laboratory. It became apparent, however, that this procedure would ignore factors encountered by concrete in service or would involve very great expense. The work was therefore broadened, and has included the following exposure conditions:

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Cylinders and briquets were stored in the laboratory at ordinary room temperatures, in pure solutions of magnesium sulphate ($MgSO_4$) and sodium sulphate (Na_2SO_4) ranging in strength from one-fourth of 1 per cent to 15 per cent. All solutions were held in covered 5-gallon earthenware jars, 10 liters (2.6 gallons) in each. The solutions were changed at intervals of one to four weeks. Never more than 20 cylinders were stored in any jar.

Cylinders and draintile were stored in the alkali water of Medicine Lake, 18 miles northwest of Watertown, S. Dak. This is a 300 or 400 acre body of clear water, some 30 to 40 feet deep, with stretches of gravel beach that afford excellent conditions for installing and examining specimens. As in many other lakes of the upper Mississippi River Basin, the water level of Medicine Lake has considerably receded during the last eight years. This increased the salt concentration from 2.34 per cent on April 29, 1924, to 7.42 per cent on October 21, 1931. Analyses of six water samples taken December 10, 1923; February 14 and April 29, 1924; and February 18, July 1 and October 21, 1931, are averaged in Table 3 and show a total salt content of 4.79 per cent, almost wholly magnesium and sodium sulphates. Medicine Lake freezes over, but all cylinders used in these experiments were installed at depths well below that to which the water froze.

TABLE 3.—*Average of six analyses* [1] *of water from Medicine Lake, S. Dak., 1923 to 1931*

Component	Quantity	Reacting value	Component	Quantity
Radicals:	*Parts per million*	*Per cent*	Anhydrous salts:	*Parts per million*
Na	4,313	11.50	$NaNO_3$	Trace.
Ca	1,030	3.48	NaCl	1,053
Mg	6,324	35.02	Na_2SO_4	12,041
NO_3	Trace.	.00	$MgSO_4$	31,298
Cl	639	1.22	$CaSO_4$	2,823
SO_4	35,108	48.08	$CaCO_3$	194
CO_3	117	.27	$Ca(HCO_3)_2$	492
HCO_3	370	.43		
Total	47,901	100.00	Total	47,901

[1] Analyses by the water and beverage laboratory, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

Draintile of 5 and 6 inches diameter were installed 6 to 7 feet deep as part of a tile system in alkali soil in Lyon County, southwestern Minnesota. About 50 feet of poorly made commercial 6-inch concrete tile had failed by disintegration at this location and were replaced in 1919 after but eight months' service. Soil conditions are represented by the water analysis first shown in Table 4. Draintile of 5 and 6 inches diameter were also buried 18 inches deep along the margin of an alkali slough in Cass County in southeastern North Dakota. The analysis of soil water taken from the trench in which these tile were installed is also shown in Table 4.

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TABLE 4.—*Analyses* [1] *of soil water samples taken at concrete draintile installations*

Component	Lyon County, Minn.		Cass County, N. Dak.		Component	Lyon County, Minn.	Cass County, N. Dak.
	Quantity	Reacting value	Quantity	Reacting value		Quantity	Quantity
Radicals:	*Parts per million*	*Per cent*	*Parts per million*	*Per cent*	Anhydrous salts:	*Parts per million*	*Parts per million*
Na (calculated)	716	4.42	27,362	48.18	$NaNO_3$		9
Ca	193	1.37	570	1.15	NaCl	3	5,533
Mg	3,783	44.21	200	.67	Na_2SO_4	2,206	77,770
NO_3	0	.00	2	.00	$MgSO_4$	18,619	991
Cl	2	.01	3,360	3.84	$MgCO_3$	78	
SO_4	16,349	48.36	54,203	45.70	$CaSO_4$		1,168
CO_3	111	.52			$CaCO_3$	92	
HCO_3	476	1.11	689	.46	$Ca(HCO_3)_2$	632	915
Total	21,630	100.00	86,386	100.00	Total	21,630	86,386

[1] Analyses by the water and beverage laboratory, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

METHOD OF MEASURING ALKALI ACTION

The principal physical effect of alkali action on Portland-cement concrete is an increase of volume caused by chemical interchange resulting in the sulphuric acid radical (SO_3) of the sulphates combining with the free lime hydrate of the cement to form calcium sulphate. In the case of magnesium sulphate, magnesium hydrate is also formed as an amorphous voluminous precipitate. Both of these secondary products occupy much greater volume than the original hydrated cement and free lime hydrate and are the chief causes for the physical rupture of the concrete illustrated in Plate 1, A. This characteristic was utilized in studying the progress of deterioration of test cylinders.

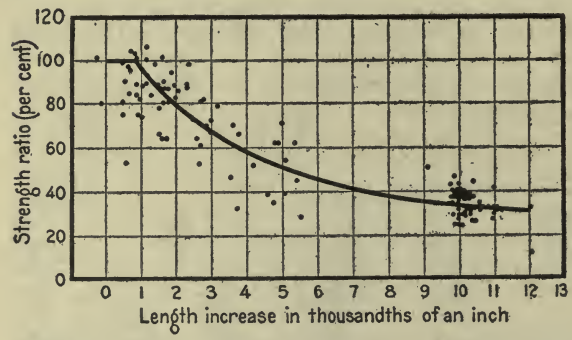

FIGURE 1.—Relation between increase in length and loss in compressive strength of concrete cylinders, 1:3 mix, stored in 1 per cent solutions of sodium sulphate. Each point is the average of 10 cylinders made on 5 days, and the 126 points represent tests of Portland cements from 35 mills

Round-head 1-inch brass screws were set in neat cement in the ends of one-third of the cylinders in the series exposed in the laboratory and of those in a few series exposed in Medicine Lake. Measurements between screw heads were taken in recording changes in the length of the cylinders. Both the amount and the rate of increase, as indicated by length changes, have been used in comparing behavior. Measurements were made with an Ames dial graduated to thousandths of an inch, and by interpolation, measurements were recorded to 0.0001 inch. The special mounting illustrated in Plate 1, C was devised to facilitate making the readings. Many readings made with this device by different observers indicate an accuracy of about 0.0002 inch.

The relation between increase in length and loss in compressive strength, based on tests of several hundred cylinders, is shown in

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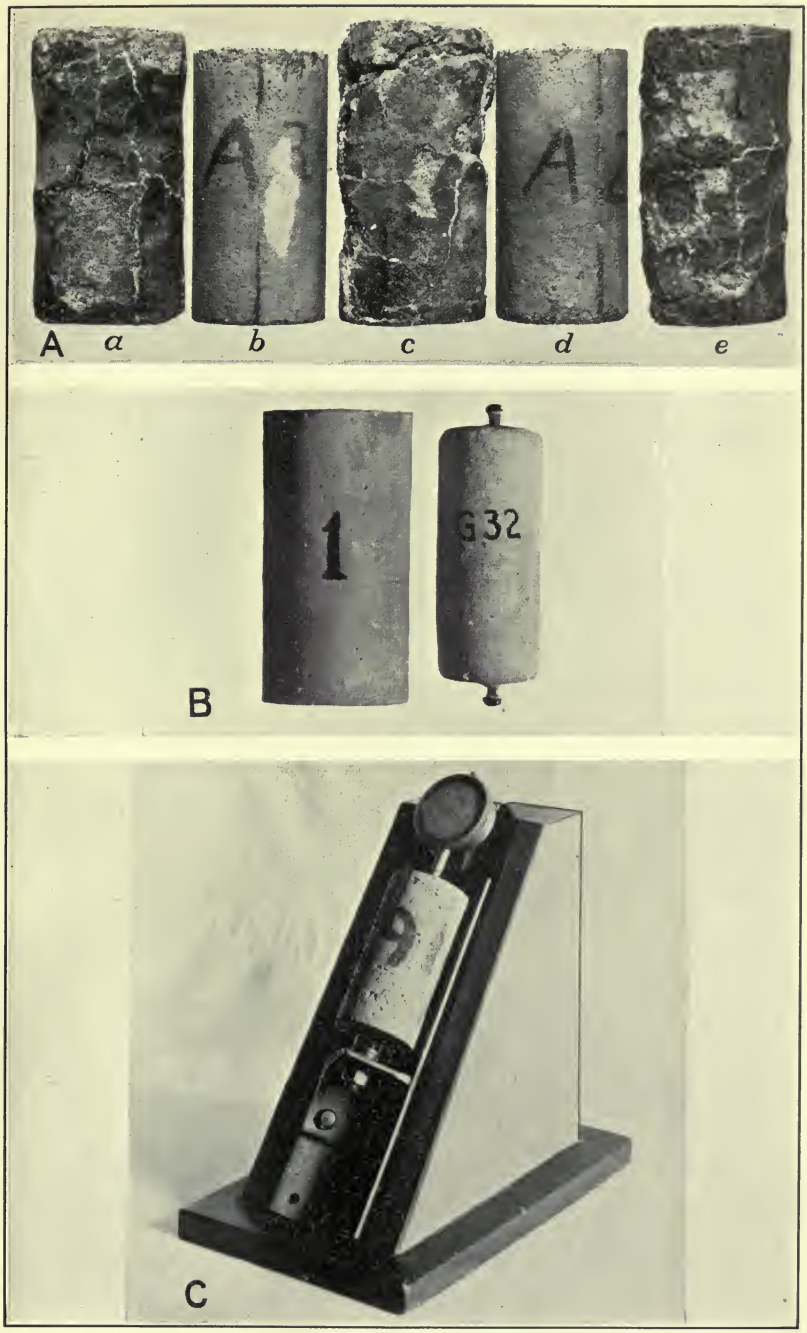

A, Three standard Ottawa sand cylinders (*a*, *c*, *e*) after storage in 1 per cent solutions of magnesium sulphate compared with two cylinders from the same lot (*b*, *d*) stored in distilled water, showing increase in volume due to sulphate action. B, Neat cement 2 by 4 inch cylinder after 10 years in 4 per cent solution of magnesium sulphate compared with cylinder stored in tap water. Cylinder from solution had but 38 per cent of its original volume. C, Special mounting for Ames dial used to measure length changes of 2 by 4 inch test cylinders

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Figure 1. The compression tests were made on blank-end cylinders from the same batches as the cylinders measured for length. The graph indicates that in these 2 by 4 inch cylinders of 1: 3 mix and 0.62 water-cement ratio, an increase in length of 0.01 inch or 0.25 per cent predicated an average loss in strength of about 66 per cent. This relation was found to hold consistently with the different brands of Portland cement in mixes leaner than 1: 2, and to vary only moderately with water-cement ratios between 0.44 and 0.73. Figure 2 shows the effect of the strength of sulphate solution upon the rate of increase in length of cylinders.

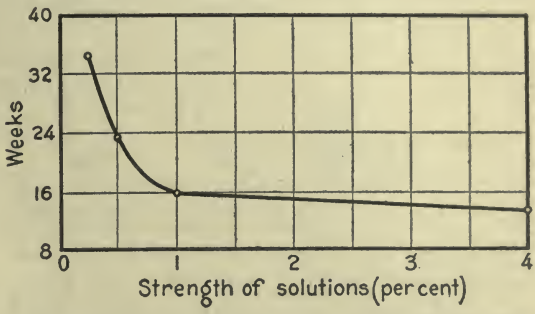

FIGURE 2.—Time required for mortar and concrete cylinders stored in magnesium sulphate solutions to increase in length 0.01 inch. Each point is the average for 25 cylinders in five series. (Cements A and B1 mixed in equal portions)

Because of the consistency of the results platted in Figures 1 and 2, the practice of rating relative resistance of the test cylinders on the basis of time required to increase in length by 0.01 inch, and of considering the usefulness or "life" of all such cylinders to have ended when that increase in length had occurred, was adopted. For a mix of 1:1 and for neat cement, an increase of 0.01 inch in the cylinders was found to indicate a loss of strength considerably greater than the loss for the leaner mixes. The reason for this is discussed under "Quantity of cement in mix."

SULPHATE ACTION IN RELATION TO STRENGTH OF SOLUTION

The destructive action of solutions of magnesium sulphate and sodium sulphate increases with the strength of the solution but at a diminishing rate. Figures 2 and 3 show that with magnesium sulphate solutions between 0.25 and 0.5 per cent strength, the rate of action on the cylinders was somewhat proportional to the strength of the solution. With strengths greater than 1 per cent the rate of action increased less rapidly, and cylinders in 4 per cent solutions had compressive strengths averaging 86 per cent of those in 1 per cent solutions. Table 5 and Figures 4 and 5 show similar results observed in briquets stored in 1, 5, and 15 per cent solutions of magnesium sulphate and of sodium sulphate, the destructive action of the 5 per cent solutions being in all cases much less than five times

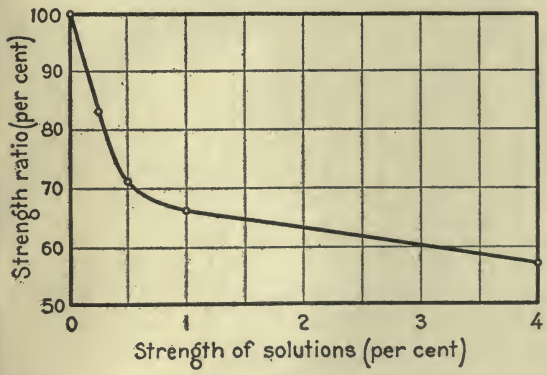

FIGURE 3.—Strength ratios of mortar and concrete cylinders after storage for 15 weeks in magnesium sulphate solutions of different strengths. Each point is the average for 25 cylinders in 5 series. (Cements A and B1 mixed in equal portions)

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that of the 1 per cent solutions and the action of the 15 per cent solutions not approaching three times that of the 5 per cent solutions.

TABLE 5.—*Condition of standard Ottawa sand briquets stored for various periods in sodium sulphate and magnesium sulphate solutions of different strengths*

[Conditions were rated visually, from 0 indicating complete disintegration to 10 indicating no apparent action of the solution upon the briquet]

Portland cement	Lots tested (number)	Condition of briquets immersed in solution for time stated											
		4 weeks						12 weeks					
		Na_2SO_4			$MgSO_4$			Na_2SO_4			$MgSO_4$		
		1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent
I	4	10	10	10	10	10	10	10	10	10	10	10	10
C	5	10	10	10	10	10	10	10	10	10	10	10	9
H	5	10	10	10	10	10	10	10	10	10	10	10	9
K2	4	10	10	10	10	10	10	10	10	10	10	10	9
J	1	10	10	10	10	10	10	10	10	10	10	10	10
G	5	10	10	10	10	10	10	10	10	10	10	10	9
E	2	10	10	10	10	10	10	10	9	8	10	9	7
F	1	10	10	10	10	10	10	10	10	9	10	10	9
D	6	10	10	9	10	10	9	9	7	6	10	9	3
M	2	10	10	9	10	10	9	9	6	3	10	9	2
B1	11	10	8	8	10	9	7	7	5	2	9	6	3
AA	2	10	10	10	10	10	10	10	8	7	10	9	8
P	1	10	10	10	10	10	9	10	9	2	10	9	5
A	7	9	5	5	10	9	3	3	2	1	8	4	2
½A and ½B1	5	10	9	8	10	10	9	8	6	4	9	7	5
Average of 61 lots		9.9	9.1	8.8	10.0	9.7	8.4	8.4	7.3	6.1	9.5	8.1	5.9

Portland cement	Lots tested (number)	Condition of briquets immersed in solution for time stated											
		20 weeks						26 weeks					
		Na_2SO_4			$MgSO_4$			Na_2SO_4			$MgSO_4$		
		1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent	1 per cent	5 per cent	15 per cent
I	4	10	10	8	10	9	8	10	10	8	10	8	7
C	5	10	10	9	10	9	6	10	10	8	10	8	6
H	5	10	8	8	10	9	6	10	7	6	10	8	4
K2	4	10	9	8	10	9	7	10	8	7	10	8	3
J	1	10	10	10	10	9	9	10	10	9	10	9	8
G	5	10	8	7	10	9	6	10	7	4	10	8	3
E	2	8	7	6	10	8	4	8	2	0	10	5	0
F	1	10	10	6	10	9	7	10	8	0	10	7	0
D	6	6	3	1	9	6	1	6	1	0	8	4	0
M	2	7	2	0	9	6	0	5	0	0	9	4	0
B1	11	5	2	0	8	4	1	4	0	0	7	3	0
AA	2	8	6	3	10	8	3	7	3	0	10	6	0
P	1	10	1	0	10	8	0	10	0	0	10	7	0
A	7	2	1	0	5	3	1	1	0	0	4	1	0
½A and ½B1	5	7	4	0	8	6	3	5	1	0	6	4	0
Average of 61 lots		7.3	5.3	3.7	8.8	6.7	3.6	6.8	3.8	2.6	8.2	5.3	1.9

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The curves in Figures 2 and 3 are of the same general type as those in Figures 4 and 5. The actual difference in rate of action probably was due to difference in the type of the specimens, though it is possible that part of the difference was only apparent and was the result of using dissimilar methods of rating the cylinders and the briquets.

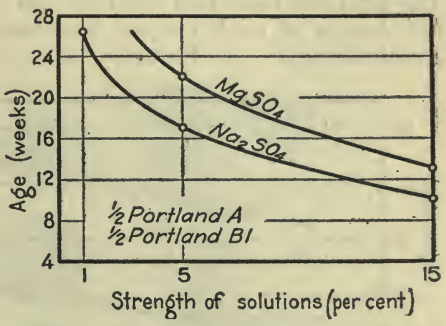

FIGURE 4.—Time required for standard Ottawa sand briquets stored in sulphate solutions to deteriorate 50 per cent. (Visual rating, see Table 5.) Each point is the average for five briquets

The general shape of the curves in Figures 2, 3, 4, and 5 is interpreted to mean that the rate of disintegration is dependent not only on the quantity of salt present but also on the quantity and availability within the specimen of those soluble constituents of the cement that react with the sulphates. This has great significance in the practical use of concrete which may be subjected to the action of sulphates, as it indicates that density of the concrete, to the greatest degree of impermeability obtainable, is a primary requisite of permanence. It suggests also that precautionary measures very nearly identical must be taken for all really serious sulphate-exposure conditions, regardless of the actual quantities of sulphates present.

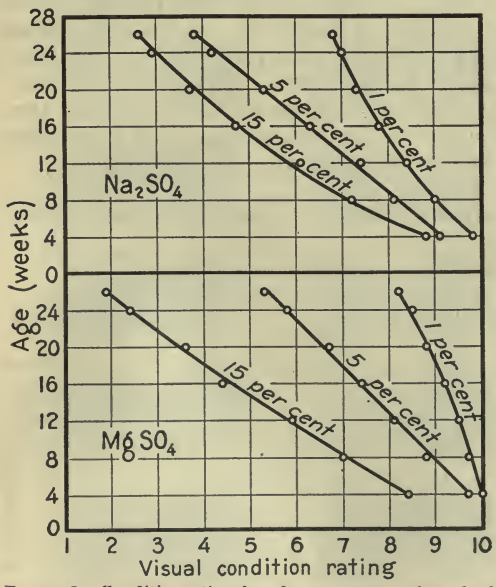

FIGURE 5.—Condition ratings based on appearance of standard Ottawa sand briquets stored in sulphate solutions for 26 weeks. Each point is the average for 61 briquets

For consistent test results in any set of concrete-alkali laboratory experiments it is essential that the strengths of all solutions be maintained reasonably constant. Excessive variations of the time interval between changes may greatly influence the rate of action. Continually changing solutions would be ideal, but there are practical difficulties in such an arrangement. The effect of varying the time interval between renewals of 1 per cent solutions of sodium sulphate is shown in Figure 6. Two types of cylinders were used, one made of Minnesota sand and pebbles graded to produce a fineness modulus of 4.67, the other made of pit-run sand passing a No. 4 screen and having a fineness modulus of 2.83.

ACTIONS OF SODIUM SULPHATE AND OF MAGNESIUM SULPHATE COMPARED

The sodium and magnesium sulphates did not differ greatly in their effect upon the concrete, although, with most of the cements

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used, the action of sodium sulphate was slightly more severe for solutions of the same strength. This is shown by Figures 4 and 5, which compare the effects of the two salts upon halves of identical briquets. The briquets used had been broken in the 7-day tensile tests, and the two halves of each briquet had been stored in different solutions of equal strength. In Figure 5 each curve was constructed by averaging results obtained with 14 brands of Portland cement. The number of lots of each cement tested ranged from 1 to 11.

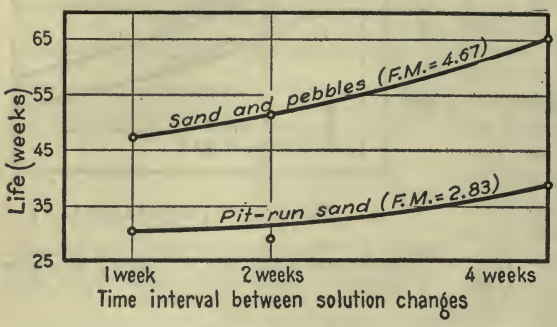

FIGURE 6.—Relation between the time elapsing between renewal of solutions and the life of two types of concrete cylinders stored in 1 per cent solutions of sodium sulphate. Each point is the average for 10 cylinders made on five days. (Cements A and B1 mixed in equal portions)

The results obtained with different lots of the same cement have been reasonably consistent, and show that some standard Portland cements have slightly greater resistance to attack by magnesium sulphate than to attack by sodium sulphate, while for other cements the reverse is true. The order of resistance to each salt is shown in Table 6. Plate 2 shows photographs of standard briquets made of 27 cements, after six months' exposure in 1 per cent solutions of the sulphates. All the data show clearly that a cement relatively high in resistance to one of the two salts is likewise high in resistance to the other, and that a cement low in resistance to one salt is low in resistance to the other.

TABLE 6.—*Order of resistance to sulphate action of 14 standard Portland cements*

[For each sulphate this is the order of the sums of the condition ratings at 26 weeks for the 3 solution strengths, as shown in Table 5]

Portland cement	Lots tested (number)	Order of resistance to—		Portland cement	Lots tested (number)	Order of resistance to—	
		Sodium sulphate	Magnesium sulphate			Sodium sulphate	Magnesium sulphate
J	1	1	1	P	1	8	8
I	4	2	2	AA	2	9	9
C	5	3	3	E	2	10	10
K2	4	4	5	D	6	11	12
H	5	5	4	M	2	12	11
G	5	6	6	B1	11	13	13
F	1	7	7	A	7	14	14

EFFECT OF SHALE IN AGGREGATE

In some localities it is difficult to find deposits of sand and gravel entirely free of shale. The Minnesota Department of Highways permits 4 per cent of shale by volume in fine aggregate and 0.5 per cent in coarse aggregate for 1-course concrete. However, considerable draintile in which the sand contained much more than 4 per

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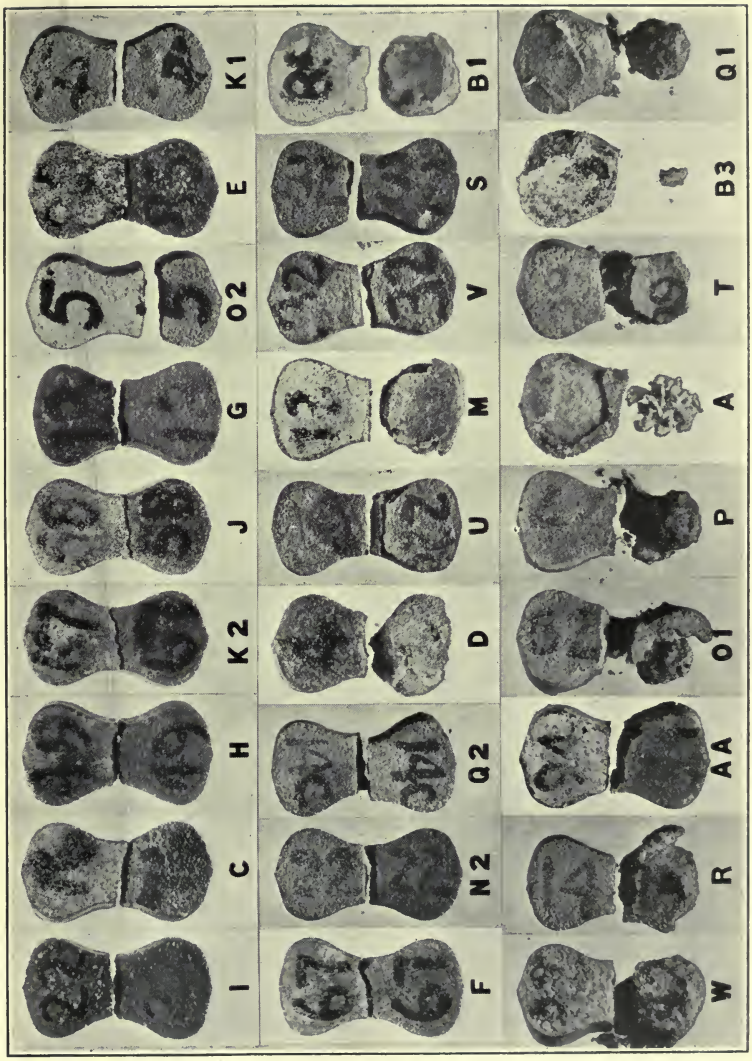

STANDARD BRIQUETS AFTER 6 MONTHS IN 1 PER CENT SULPHATE SOLUTIONS

Upper halves were in magnesium sulphate and lower halves in sodium sulphate. A different standard Portland cement was used in each briquet

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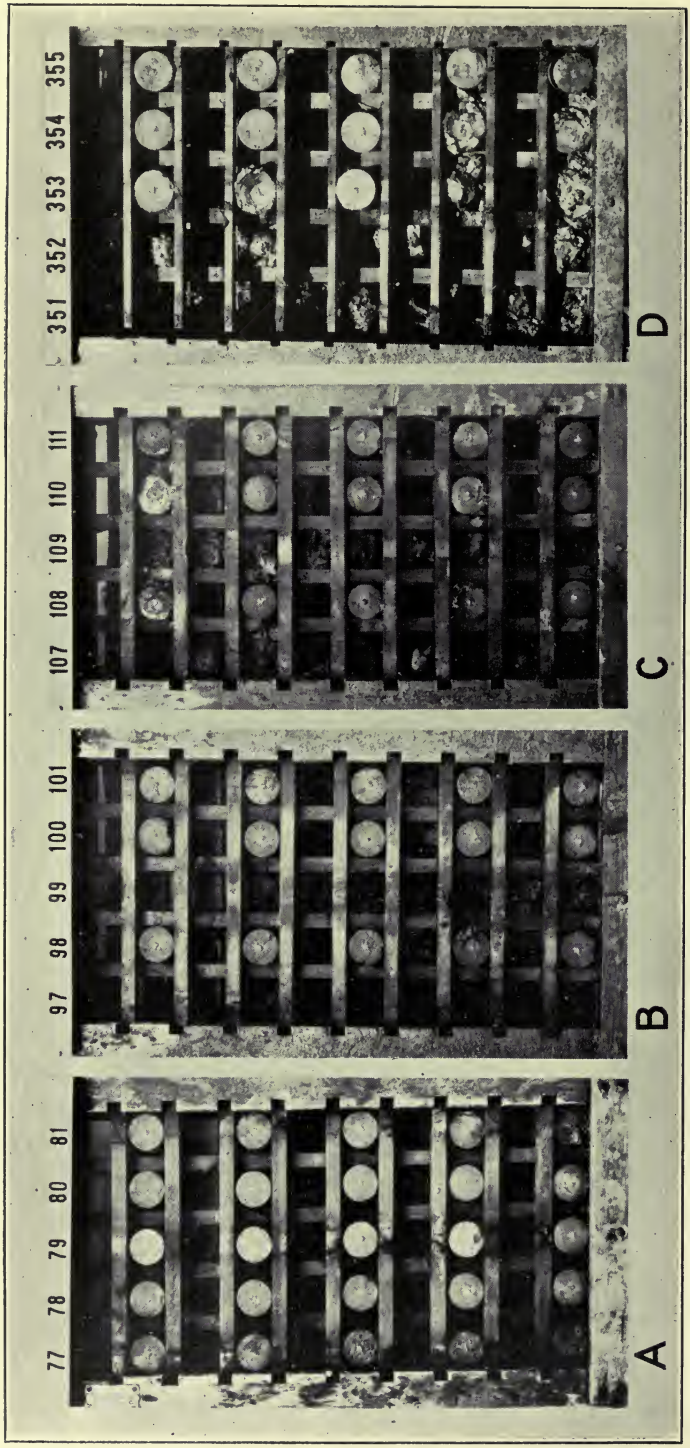

CYLINDERS CURED IN STEAM OR WATER VAPOR AFTER STORAGE IN MEDICINE LAKE

A, Cured in steam at 212° F. after 7½ years in the lake. B, Cured in water vapor at 155° after 7½ years in the lake. Series 98, 100, and 101 were also cured in steam at 212°. C, Ottawa sand cylinders cured in water vapor at 155° after 7½ years in the lake. Series 108, 110, and 111 were also cured in steam at 212°. D, Cured in water vapor or steam for 12 hours at temperatures of 190°, 212°, 235°, 260° and 285°, respectively, after 6 years in lake

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cent shale has been marketed in Minnesota; one plant actually used sand containing 28 per cent shale and another plant 23 per cent. In experiments with the aggregates from these two plants it was found that removal of all the shale reduced the absorption of water by the concrete from 8.1 to 2.4 per cent in the one case and from 7.2 to 2.7 per cent in the other. It is evident that satisfactory draintile can not be manufactured from such aggregates.

To indicate what influence shale may have on alkali resistance, cylinders made of a sand containing 9 per cent shale by volume were exposed, with cylinders of the same sand from which the shale had been removed by elutriation, to ¼, ½, 1, and 4 per cent solutions of magnesium sulphate. The relative resistance of two types of cylinders, with and without shale, is shown in Figure 7. It is clear that removing the 9 per cent of shale did not markedly alter the resistance of these specimens. However, removing 9 per cent of shale did reduce absorption by the aggregate from 3.1 to 1.6 per cent. This indicates the desirability of low shale content for any concrete subjected even to mild weathering agencies, irrespective of the influence of the shale on resistance to sulphates.

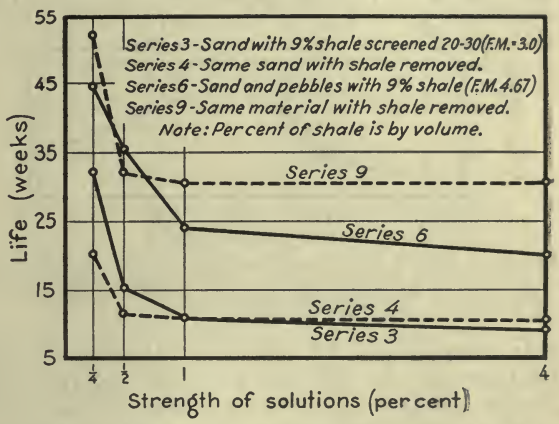

FIGURE 7.—Effect of shale in aggregate on the life of mortar and concrete cylinders stored in solutions of magnesium sulphate. Each point is the average for five cylinders made on different days. (Cements A and B1 mixed in equal portions)

QUANTITY OF WATER IN MIX

Because in the manufacture of small concrete draintile it is common practice to remove the jackets immediately after tamping, an excess of mixing water is rarely used. On the contrary, there is a decided tendency to use too little water. At one Minnesota plant as little as 2.4 gallons of water per bag of cement was used regularly in making 6-inch tile. For this reason the cylinders in practically all the experiments herein reported have been made of concrete and mortar having low water-cement ratios.

To determine the influence of variations in the quantity of water on the resistance of dry-mixed concrete, the cylinders upon which Figure 8 is based were made and stored in 1 per cent solutions of magnesium sulphate. Cylinders in these five series had relative consistencies of 0.75, 0.90, 1.0, 1.10, and 1.25, and water-cement ratios of 0.44, 0.53, 0.59, 0.64, and 0.73, respectively. These water-cement ratios were equivalent to 3.3, 4.0, 4.4, 4.8, and 5.5 gallons of water per bag of cement.

Figure 8 shows that of this group of cylinders those with a relative consistency of 1.0, obtained with a water-cement ratio of 0.59, gave the best strength and absorption results and were most resistant to disintegration, although the cylinders with a relative consistency of

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1.10, obtained with a water-cement ratio of 0.64, were only slightly less resistant. The driest-mixed cylinders gave the poorest strength and absorption results and had a life only 57 per cent of that of the best series. After these tests, it became the standard laboratory practice in mixing cylinders of this type to use a water-cement ratio of 0.59, which was later increased to 0.62 to improve workability and produce cylinders with smoother surfaces.

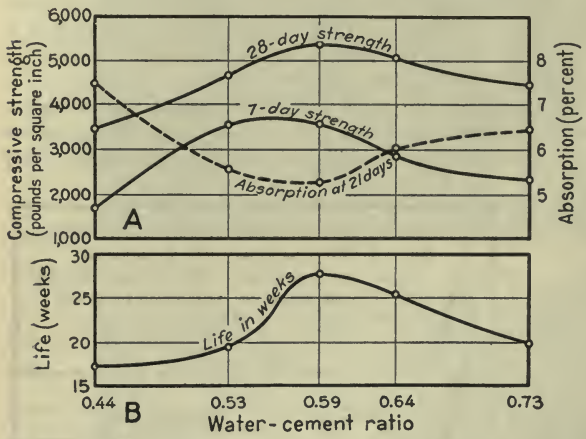

FIGURE 8.—Effect of water-cement ratio (A) on strength and absorption and (B) on life of concrete in 1 per cent solutions of magnesium sulphate. Each point is the average for five cylinders made on different days. (Cements A and B1 mixed in equal portions)

QUANTITY OF CEMENT IN MIX

The richer the mix the more resistant is concrete to sulphates, other factors being the same. This is illustrated by the curves in Figure 9 based on tests of 1:5, 1:4, 1:3, 1:2, 1:1, and neat cement cylinders exposed to the action of 1 per cent solutions of magnesium sulphate. Enumerated in the foregoing order, the relative resistances of the cylinders of this group were 1, 1.25, 3.3, 7, 36, and 66, the neat cement cylinders having a life 66 times that of the cylinders mixed 1:5. It is evident that only when the mix becomes as rich as 1:2 are outstanding results obtained, and the greatest value is not realized until it becomes as rich as 1:1.

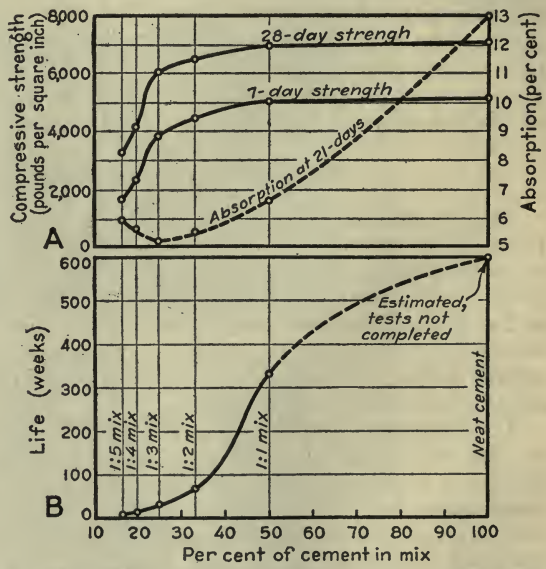

FIGURE 9.—Effect of quantity of cement in mix (A) on strength and absorption and (B) on life of concrete cylinders stored in 1 per cent solutions of magnesium sulphate. Each point is the average for five cylinders made on different days. (Cements A and B1 mixed in equal portions)

Neat cement cylinders, after 10 years' exposure in 1 per cent magnesium sulphate solutions, showed an average decrease in length. Because of the density of neat cement the sulphate action was confined largely to the surfaces of the cylinders, and progressed continuously though slowly. This caused the cement to swell and fall off in very thin layers while, as indicated by length changes, the

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interiors of the cylinders were affected relatively little. An extreme example is illustrated in Plate 1, B by the cylinder stored 10 years in a 4 per cent solution. This cylinder had a calculated volume only 38 per cent of its original volume, yet the measured length between screw heads was only 0.0061 inch less than the original length.

Neat cement cylinders from the same lot as those shown in Plate 1, B, after storage for four years in a 1 per cent solution of magnesium sulphate had 70 per cent of normal strength—the average for cylinders stored the same length of time in tap water—whereas the strength of the 1:1 cylinders was but 50 per cent of normal strength. From these 4-year compression tests and from volume-change observations over a longer period, the life of the neat cement cylinders has been estimated at 600 weeks for comparison with the other cylinders of this group. (Fig. 9.) All the cylinders were stored at room temperatures and prevented from drying out, therefore surface crazing was avoided and such destructive action as took place was solely the result of chemical action by the magnesium sulphate.

LENGTH OF TIME OF MIXING

It is generally agreed that after the ingredients for concrete have been combined intimately and uniformly, continuing the mixing has small value.

It is the practice in the laboratory to hand mix each batch of nine cylinders 1½ minutes dry and 2 minutes after adding the water. To determine the adequacy of such mixing, cylinders of three series were made and tested, with the results recorded in Table 7. The cylinders of these series were identical except as to the lengths of mixing time after adding the water, which were 1, 2, and 5 minutes. It is not evident that this difference in mixing affected strength and absorption more than slightly. However, the relative resistances of the three series as measured by length changes after storage in 1 per cent solutions of sodium sulphate were 1, 1.1, and 1.2 in favor of the 5-minute mix.

TABLE 7.—*Effect of time of mixing on resistance of 2 by 4 inch concrete cylinders exposed in 1 per cent solutions of sodium sulphate* (Na_2SO_4)

[Each test result is average for five cylinders made on different days]

Series	Mixing of materials	Fineness modulus	Water-cement ratio	Absorption at 21 days	Stored in tap water		Stored in Na_2SO_4			
					Age when broken	Strength in compression	Age when broken	Strength in compression	Strength ratio [1]	Time required to increase in length 0.010 inch
				Per cent	*Weeks*	*Lbs. per sq. in.*	*Weeks*	*Lbs. per sq. in.*	*Per cent*	*Weeks*
426	1½ minutes dry and 1 minute wet	4.67	0.62	6.5	1	2,910	--------	--------	--------	--------
					4	4,230	--------	--------	--------	--------
					52	5,120	52	2,590	51	--------
					74	5,170	74	1,700	26	70.9
427	1½ minutes dry and 2 minutes wet	4.67	.62	6.5	1	2,870	--------	--------	--------	--------
					4	4,390	--------	--------	--------	--------
					52	6,040	52	3,210	53	--------
					82	5,850	82	1,530	26	79.0
428	1½ minutes dry and 5 minutes wet	4.67	.62	6.4	1	3,100	--------	--------	--------	--------
					4	4,700	--------	--------	--------	--------
					52	5,740	52	3,760	66	--------
					90	5,380	90	2,080	39	87.1

[1] Ratio of the strength of cylinders stored in sodium sulphate to those of the same series stored in tap water.

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LONG-TIME WATER CURING

The effect of long-time water curing on the resistance of Portland-cement concrete and mortar cylinders to 1 per cent solutions of magnesium sulphate is shown in Table 8. The table compares cylinders from eight series cured 1 year in water and from 10 series cured 6 months in water with cylinders from the same series water cured 20 days. None of the cylinders had any hardening in air.

TABLE 8.—*Influence of long-time water curing on life of various types of Portland-cement mortar and concrete 2-by-4-inch cylinders stored in 1 per cent solutions of magnesium sulphate*

General description	Life in weeks of samples cured in distilled water for—		
	20 days	6 months	1 year
Sand cylinders:			
Ottawa standard sand	12.9	----------	12.7
Minnesota sand, screened, 20–30	4.8	----------	23.4
Minnesota sand, screened, 20–30	10.8	----------	27.9
Minnesota sand, screened, 20–30, shale removed	10.8	----------	23.1
Minnesota sand, pit run	15.6	----------	28.3
Minnesota sand, special grading	23.8	----------	40.0
Minnesota sand, screened, 20–30	8.5	----------	20.7
Minnesota sand, special grading, shale removed	30.5	----------	36.4
Average	14.7	----------	26.6
Laboratory standard cylinders:			
Water-cement ratio, 0.44	17.3	29.3	----------
Water-cement ratio, 0.53	19.5	22.4	----------
Water-cement ratio, 0.59	27.7	28.6	----------
Water-cement ratio, 0.64	25.4	25.1	----------
Water-cement ratio, 0.73	19.8	20.0	----------
Mix 1:1	330.0	318.7	----------
Mix 1:2	66.3	60.0	----------
Mix 1:3	30.0	24.7	----------
Mix 1:4	11.4	13.1	----------
Mix 1:5	9.1	11.4	----------
Average	55.6	55.3	----------

The data in Table 8 show an average increase in the life of the mortar cylinders cured 1 year of 81 per cent over that of cylinders cured 20 days, but show slight change in the life of concrete cylinders cured 6 months. Just why cylinders cured 1 year in water should show greatly increased resistance while those similarly cured half as long should show no increased resistance is difficult to explain. However, the cylinders in the two groups were dissimilar in many respects. In general, those cylinders representative of the highest quality concrete seemed to have been benefited least by long-time water curing, whether the curing period was 1 year or 6 months, and differences in cylinders probably account for the apparent discrepancy in resistance after being water-cured 1 year and being water-cured 6 months. It is evident that resistance of low-quality concrete may be raised somewhat by long-time water-curing, but concrete of reasonably good quality will be improved very little by such treatment.

LONG-TIME AIR HARDENING

Vicat (*51*) suggested as long ago as 1857 that the action of magnesium sulphate on cement mortar continues until all lime is acted upon except that which is combined with carbon dioxide. Feret (*23*),

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Bates, Phillips, and Wig (*8*), Blount (*12*), and others have suggested carbonization of some of the free lime near the surface of concrete aged in air or water, as one cause for observed increased resistance to sulphate attack. Burke (*15*) in 1925 concluded, after an interesting series of experiments with carbon dioxide treated briquets, that "It seems logical to assume that if good concrete is allowed to set in the presence of CO_2 or properly exposed thereafter, the surface would become very resistant to sulphate attack."

Air under ordinary conditions contains more or less carbon dioxide, and therefore it should follow that the resistance of concrete would be appreciably increased by hardening the concrete in air at ordinary temperatures, whether storage were under room-dry conditions or out of doors. It should also follow that greater resistance would result from storage in the air of an occupied heated room than from storage out of doors, because the CO_2 content of the room air would generally be higher. Increased resistance of concrete usually does occur under these two conditions of air hardening, as is illustrated by the curves in Figure 10. Whether this is due entirely to carbonation of some of the lime is not known. Figure 10 is based on the behavior in 1 per cent solutions of sodium sulphate, of three groups of cylinders for each of which the air-hardening periods, following 20 days in water, were 0, 2, 4, 8, and 49 weeks. One group was air-hardened out of doors, and two groups, one of which was of standard Ottawa sand, in the laboratory. The concrete cylinders exposed longest in air under room-dry conditions were most resistant of any of the cylinders, and their life was nearly seven times that of cylinders of the same group not air-hardened. Cylinders of the three groups were first exposed to air between March 7 and April 11, when temperatures were about average and humidities somewhat above average. The average relative resistances of cylinders from the three groups were 1, 1.2, 1.4, 1.7, and 4.3 for respective air-hardening periods of 0, 2, 4, 8, and 49 weeks.

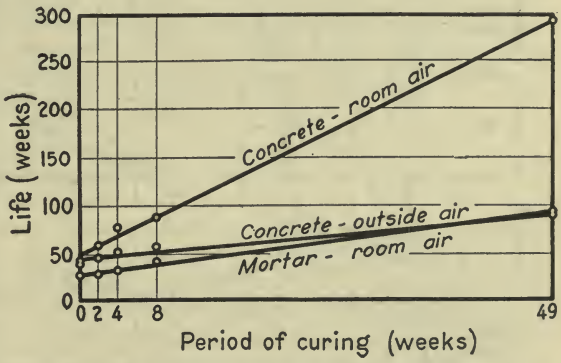

FIGURE 10.—Effect of air curing, after 20 days' storage in water, on life of concrete and Ottawa sand-mortar cylinders stored in 1 per cent solutions of sodium sulphate. Each point is the average for 10 cylinders made on five days. (Cements A and B1 mixed in equal portions)

Some of the curves in Figure 11 (series 23, 24, 25, 28, 29, 30, 33, 34, and 35) show the behavior of three groups of cylinders in each of which hardening in air for periods of 0, 14, and 18 days followed hardening in water for periods of 20, 6, and 2 days, respectively. One group was exposed to 1 per cent solutions of sodium sulphate and two groups, one of which was of standard Ottawa sand, to 1 per cent solutions of magnesium sulphate. The concrete cylinders stored in magnesium sulphate were exposed to air in the laboratory between July 10 and August 4, while the other cylinders were so exposed between March 5 and April 7. For all the cylinders in these three

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groups, the relative average resistances of those air hardened for 0, 14, and 18 days respectively were 1, 2.6, and 4.0. These results are surprising in view of the fact that the cylinders in this group that were air-hardened for 18 days had an average relative resistance very

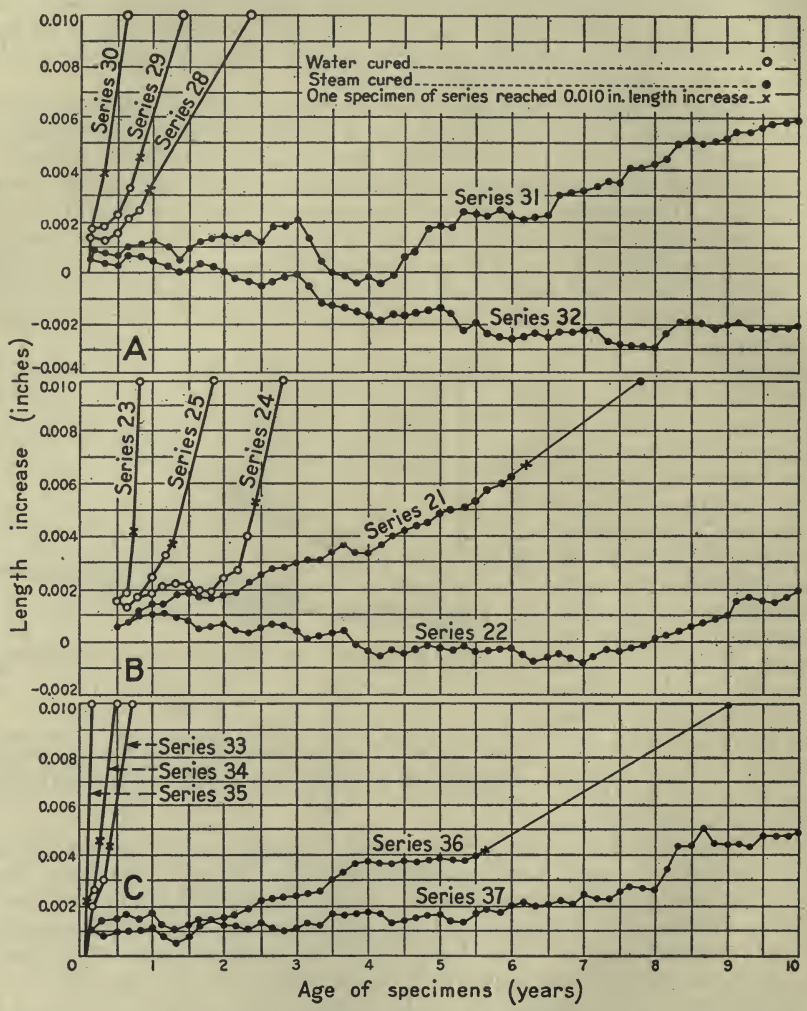

FIGURE 11.—Increase in length with age of 2-by-4-inch Portland-cement mortar and concrete cy inders, 1:3 mix, stored in sulphate solutions: A, Concrete cylinders in 1 per cent sodium sulphate; B, concrete cylinders in 1 per cent magnesium sulphate; C, Ottawa sand-mortar cylinders in 1 per cent magnesium sulphate. Curing conditions, following 1 day in moist closet, were: For series 24, 28, and 33, 2 days in distilled water and 18 days in air; for series 25, 29, and 34, 6 days in distilled water and 14 days in air; for series 23, 30, and 35, 20 days in distilled water; for series 21, 31, and 36, 2 days in water vapor at 212° F. and 18 days in air; for series 22, 32, and 37, 6 days in water vapor at 212° and 14 days in air. A length increase of 0.01 inch indicates 60 to 70 per cent loss in compressive strength. Each point is the average for 5 or 10 cylinders made on five days. (Cements A and B1 mixed in equal portions)

nearly as great as those shown in Figure 10 that were air-hardened 49 weeks.

Comparing the effects of air hardening as shown by Figures 10 and 11, it would appear that for the cements used in those experiments the most effective time for air hardening concrete that is to be subjected

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to alkali action may be shortly after the final set of the cement and before, instead of after, curing in water. The reason for this is not apparent, but the seeming fact may explain why commercial concrete of very ordinary quality, to which little or no water was applied while it was curing, has frequently displayed a high degree of resistance to sulphate attack.

Different cements, however, may respond differently to the same variations in method of curing. Available data on this are limited to those obtained by comparative compression tests on cylinders exposed for one year to the alkali water of Medicine Lake, as recorded in Table 9. Eight different cements were included in those tests, and the comparison shown is that made between cylinders cured 20 days in water with no air hardening following, and cylinders cured 20 days in water and exposed for 35 days in air in the laboratory. Some of the cements were greatly benefited by air hardening, whereas others gave slightly contrary results. Cements A and B1 were those used for the tests presented in Figures 10 and 11, and Table 9 shows that cylinders of the same cements, air hardened 35 days, averaged 47 per cent stronger after one year in the lake than did similar cylinders not air hardened. This closely checks an average calculated value of 41 per cent for the cylinders in Figure 10, air hardened 28 days and stored in a 1 per cent solution of sodium sulphate.

TABLE 9.—*Effect of air hardening on alkali resistance of concrete cylinders made of cements from different mills, as determined by compression tests after one year in Medicine Lake, S. Dak.*

Portland cement		Results of compression tests				Increase in strength due to air hardening
		Without air hardening		Hardened in air 35 days		
Brand	Lots tested	Cylinders tested	Strength ratio	Cylinders tested	Strength ratio	
	Number	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*
A	6	60	24.0	60	35.7	48.8
B1	6	60	48.2	60	69.8	44.8
D	3	30	68.7	30	85.7	24.7
H	3	30	84.3	30	93.7	11.2
I	3	30	95.0	30	101.7	7.1
K2	3	30	92.7	30	93.7	1.1
C	3	30	92.3	30	87.3	−5.4
G	3	30	98.7	30	91.3	−7.5

The cements shown in Table 9 most benefited by air hardening were those having the least resistance to the action of alkali. (Pp. 38 to 44.) In fact, the order of recording the cements in Table 9, which is the order of increased resistance caused by air hardening, is very closely the order of least alkali resistance. The table shows that even after 35 days of air hardening those cements of lowest alkali resistance still made poor showings when compared with the more resistant cements. Whether earlier air hardening of the more resistant cements would show results more like those obtained with the cements represented by Figures 10 and 11 can not be stated definitely.

The full significance of these air-hardening experiments can not now be stated, but the following statement is conservative: For each increase of two weeks of air hardening, up to one year, the durability

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of concrete made of low alkali-resisting cements may ordinarily be expected to increase by 10 or 20 per cent over that of concrete without air hardening, the degree of increase varying with different concretes and with temperature, humidity, and other conditions during storage. It has not been shown, however, that the life of concrete made of cements high in alkali resistance is greatly influenced by air hardening.

CURING IN WATER VAPOR

It was learned from experiments begun in 1922 that concrete cured in steam over water boiling at atmospheric pressure displayed remarkable resistance in the laboratory to solutions of magnesium and sodium sulphate (*33, 37*). Some of the cylinders of these earlier series are still under observation, and their condition as indicated by length changes is shown in Figure 11. For each of these groups, resistance to sulphate action was in the same order as duration of time in steam, whereas for the water-cured groups the resistance was in the order of time in air, as discussed in the preceding section.

Following the earlier laboratory work there were made for exposure in Medicine Lake a total of 6,525 cylinders in 145 series, of which 15 series were cured in water and air for comparison and 130 series were cured in water vapor at temperatures of 100°, 155°, 190°, 212°, 230°, 260°, 285°, 315°, and 350° F. for periods, at most temperatures, ranging from 45 minutes to 8 days. Five-year tests have been completed for 83 series, and 1 and 3 year tests for all series.

The data obtained (Table 10), although incomplete for many series cured at the higher temperatures, apparently justify the following conclusions regarding alkali resistance of concrete. These conclusions are also supported by the appearance of cylinders after exposure for periods up to seven and one-half years in Medicine Lake, as shown in Plate 3.

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TABLE 10.—*Tests of 2 by 4 inch concrete cylinders cured in water vapor at various temperatures and exposed to the action of sulphate water of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions, is an average of 5 cylinders made on different days. Figures in parentheses, indicate per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water]

TEMPERATURE, 100° F.

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hours	*Days*	*Hours*	*° F.*	*Days*	*Per cent*							
87	11	½A and ½B1	0.59	3	--------	69	100	25	6.6	3,730	4,120	5,110	5,470	1,430 (28)	0	0
88	11	do	.59	6	--------	66	100	25	6.7	3,590	4,320	4,960	5,450	1,370 (28)	0	0
89	11	do	.59	12	--------	60	100	25	6.7	4,050	4,680	5,270	5,200	1,290 (25)	0	0
90	11	do	.59	24	--------	48	100	25	6.7	4,080	4,220	5,240	6,270	1,630 (31)	0	0
91	11	do	.59	48	--------	24	100	25	6.8	3,510	4,060	5,010	4,970	1,920 (38)	0	0
92	11	do	.59	24	27	--------	--------	28	6.7	2,620	4,540	5,690	5,400	3,780 (66)	0	0
93	11	do	.59	72	--------	--------	--------	25	7.0	3,380	3,560	5,120	5,140	3,150 (62)	0	0
94	11	do	.59	24	--------	48	100	24	6.8	3,810	4,000	5,640	5,910	2,020 (36)	0	0
313	65	M	.60	24	20	--------	--------	35	5.9	3,150	3,950	6,050	5,680	2,250 (37)	0	0
315	65	M	.60	24	--------	48	100	53	6.2	3,740	3,800	5,970	6,320	4,230 (71)	3,390	3,330 (53)
[1] 112	17	½A and ½B1	.64	24	27	--------	--------	--------	10.0	1,650	2,630	3,540	2,790	1,790 (51)	0	0
[1] 113	17	do	.64	72	--------	--------	--------	25	10.7	2,000	2,000	2,980	2,940	840 (28)	0	0
[1] 114	17	do	.64	24	--------	48	100	25	10.1	2,270	2,790	3,040	3,050	630 (21)	0	0

TEMPERATURE, 155° F.

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
82	11	½A and ½B1	0.59	3	--------	69	155	25	6.9	3,360	4,210	5,380	5,550	500 (9)	0	0
83	11	do	.59	6	--------	66	155	25	6.9	3,840	4,720	5,700	5,620	490 (9)	0	0
84	11	do	.59	12	--------	60	155	25	6.7	4,440	4,960	5,250	5,920	1,030 (20)	0	0
85	11	do	.59	24	--------	48	155	25	6.6	4,350	4,550	6,460	5,830	1,220 (19)	0	0
86	11	do	.59	48	--------	24	155	25	6.7	3,540	4,210	6,250	6,320	1,660 (27)	0	0
92	11	do	.59	24	27	--------	--------	28	6.7	2,620	4,540	5,690	5,400	3,780 (66)	0	0
93	11	do	.59	72	--------	--------	--------	25	7.0	3,380	3,560	5,120	5,140	3,150 (62)	0	0
95	11	do	.59	24	--------	48	155	25	6.4	4,240	4,370	5,510	5,510	1,660 (30)	0	0
97	11, 8	do	.59	24	--------	48	155	25	6.3	3,900	4,770	5,690	5,970	1,880 (33)	0	0
99	11, 8	do	.59	24	--------	72	155	24	6.4	4,490	4,830	5,410	5,990	1,530 (28)	0	0

[1] Standard Ottawa sand cylinders.

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TABLE 10.—*Tests of 2 by 4 inch concrete cylinders cured in water vapor at various temperatures and exposed to the action of sulphate water of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

TEMPERATURE, 155° F.—Continued

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hours	*Days*	*Hours*	*° F.*	*Days*	*Per cent*							
102	17	½A and ½B1	0.59	24	--------	48	155	25	6.2	4,550	4,730	5,580	5,960	980 (18)	0	0
104	17	do	.59	24	--------	72	155	24	6.1	4,910	5,180	5,180	5,630	1,270 (25)	0	0
174	18	do	.59	24	--------	48	155	35	6.1	4,020	4,390	4,330	5,650	3,910 (90)	--------	2,740 (48)
179	18	do	.59	24	--------	48	155	35	5.8	4,110	4,510	5,210	6,460	3,820 (73)	--------	1,750 (27)
184	18	do	.59	24	--------	48	155	35	6.0	4,070	4,530	5,100	6,110	4,240 (83)	--------	800 (13)
313	65	M	.60	24	20	--------	--------	35	5.9	3,150	3,950	6,050	5,680	2,250 (37)	0	0
314	65	M	.60	24	--------	48	155	53	6.0	4,460	4,010	6,170	6,810	5,430 (88)	3,920	3,690 (54)
[1] 107	17	½A and ½B1	.64	24	--------	48	155	25	9.8	2,660	3,080	3,580	3,580	770 (22)	0	0
[1] 109	17	do	.64	24	--------	72	155	24	9.6	2,670	3,220	3,490	3,580	930 (27)	0	0
[1] 112	17	do	.64	24	27	--------	--------	--------	10.0	1,650	2,630	3,540	2,790	1,790 (51)	0	0
[1] 113	17	do	.64	72	--------	--------	--------	25	10.7	2,000	2,000	2,980	2,940	840 (28)	0	0
[1] 115	17	do	.64	24	--------	48	155	25	10.1	2,730	2,900	3,400	3,020	860 (25)	0	0
[1] 127	17	do	.64	24	--------	48	155	53	9.1	2,530	2,710	3,460	3,290	2,280 (66)	--------	0
[1] 129	17	do	.64	24	--------	72	155	52	9.0	2,700	3,120	3,320	3,230	1,970 (59)	--------	0

TEMPERATURE, 190° F.

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
351	74	½ A and ½ B1	0.62	24	--------	12	190	54	6.6	2,650	2,940	5,320	6,870	1,730 (33)	0	0
391	74	do	.62	24	20	--------	--------	35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0

TEMPERATURE, 212° F. (COMBINED IN SOME SERIES WITH 155° F.)

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
77	11	½A and ½B1	0.59	3	--------	69	212	25	7.9	1,110	1,250	1,250	2,810	1,210 (97)	1,340	2,630 (94)
78	11	do	.59	6	--------	66	212	25	7.2	2,260	3,040	3,130	5,900	2,840 (91)	2,930	4,120 (70)
79	11	do	0.59	12	--------	60	212	25	6.9	3,400	4,120	4,550	6,020	4,410 (97)	4,940	5,400 (90)
80	11	do	.59	24	--------	48	212	25	6.9	3,060	4,020	4,600	5,790	4,330 (94)	4,860	5,150 (89)
81	11	do	.59	48	--------	24	212	25	6.7	2,910	3,850	4,630	6,730	4,410 (95)	5,340	6,000 (89)
92	11	do	.59	24	27	--------	--------	28	6.7	2,620	4,540	5,690	5,400	3,780 (66)	0	0

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96	11	do	.59	24		48	212	25	6.5	3,770	4,410	4,560	5,720	4,300 (94)		4,930 (86)
98	11,8	do	.59	24		24 24	155 212	25	6.7	4,180	4,120	5,020	6,190	4,340 (87)		5,310 (86)
100	11,8	do	.59	24		48 24	155 212	24	6.2	4,310	4,960	5,730	5,750	5,540 (97)		5,890 (102)
101	11,8	do	.59	24		24 48	155 212	24	6.3	4,110	4,710	4,890	6,490	4,640 (95)		5,330 (82)
103	17	do	.59	24		24 24	155 212	25	6.0	4,600	5,510	5,290	6,280	4,980 (94)	5,510	4,910 (78)
105	17	do	.59	24		48 24	155 212	24	6.0	4,820	5,070	4,910	6,720	5,220 (106)	6,000	5,680 (85)
106	17	do	.59	24		24 48	155 212	24	5.7	5,110	5,900	5,320	6,020	5,250 (99)	5,830	5,720 (95)
296	61	do	.62	24		48	212	53	6.5	3,330	3,660	5,020	5,760	4,390 (88)	5,840	5,950 (103)
297	63	A	.60	24		48	212	53	6.4	3,650	3,660	4,680	6,020	4,600 (98)	4,960	5,480 (91)
298	62	B	.62	24		48	212	53	6.9	3,700	3,830	4,580	6,440	4,480 (98)	4,840	5,600 (87)
299	33	D	.60	24		48	212	53	6.4	3,690	3,770	4,620	6,330	4,270 (92)	4,910	5,900 (93)
300	34	C	.67	24		48	212	53	6.6	3,880	4,540	4,940	6,110	4,890 (99)	5,690	5,810 (95)
301	61	½A and ½B1	.62	24		48	212	53	6.5	3,690	3,610	4,500	4,840	4,480 (100)	5,160	5,300 (110)
302	35	E	.60	24		48	212	53	6.2	3,540	3,530	4,550	5,040	4,450 (98)	4,660	4,640 (92)
303	37	F	.60	24		48	212	53	6.0	3,550	3,900	5,060	4,890	4,920 (97)	5,920	5,470 (112)
304	39	G	.60	24		48	212	53	6.2	3,740	3,920	4,990	5,870	4,680 (94)	5,060	5,060 (86)
305	41	H	.60	24		48	212	53	6.1	3,730	3,840	4,860	5,380	4,410 (91)	4,340	5,100 (95)
306	61	½A and ½B1	.62	24		48	212	53	6.2	3,280	3,920	4,480	6,570	4,410 (98)	5,990	5,230 (80)
307	40	I	.60	24		48	212	53	5.9	3,420	4,150	5,090	5,850	4,190 (82)	4,990	4,530 (77)
308	42	J	.62	24		48	212	53	6.4	2,650	3,240	4,680	5,310	3,480 (74)	4,440	4,580 (86)
309	55	K1	.62	24		48	212	53	6.5	3,260	4,200	4,950	5,800	4,910 (99)	4,910	4,960 (86)
310	60	L	.60	24		48	212	53	6.2	3,260	3,870	5,060	6,380	4,460 (88)	4,720	5,770 (90)
311	65	M	.60	24		48	212	53	5.5	4,660	5,580	5,810	6,740	5,570 (96)	5,420	5,960 (88)
313	65	M	.60	24	20			35	5.9	3,150	3,950	6,050	5,680	2,250 (37)	0	0
352	74	½A and ½B1	.62	24		12	212	54	6.9	2,450	2,910	5,230	6,070	4,240 (81)	3,850	0
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
584	139	do	.62	24	20	[2] 1	212	35	6.3	3,740	5,150	5,790	6,270	3,350 (58)	0	0
585	139	do	.62	24		[2] 1	212	55	6.4	2,770	2,860	5,430	6,610	5,370 (99)	0	0
586	139	do	.62	24				1								
587						[2] 1	212	54	6.6	2,970	2,920	5,800	6,440	4,400 (76)	0	0
635–636	139	do	.64	24		48	212	53	6.3	3,960	4,330	4,250	6,600	4,370 (103)	5,950	6,550 (99)
640	139	do	.64	24	20			35	6.5	3,320	4,470	5,800	6,070	4,530 (78)	0	0
641	139	do	.64	24		48	212	53	6.9	3,590	3,760	4,530	6,010	3,740 (83)	5,360	6,140 (102)
830	232	do	.62	24	20			35	5.9	3,230	4,720	6,360		3,950 (62)	0	0
831	232	do	.62	24		¾	212	55	6.9	3,020	2,880	5,740		4,210 (73)	2,280	
832	232	do	.62	24		1½	212	55	7.4	2,590	2,400	5,890		4,610 (78)	4,330	
833	232	do	.62	24		3	212	55	7.2	2,890	3,130	6,350		4,510 (71)	2,840	
834	232	do	.62	24		6	212	55	7.0	3,220	3,470	5,730		4,970 (87)	6,270	
835	232	do	.62	24		12	212	55	7.1	3,570	3,580	5,070		5,250 (104)	5,970	
836	232	do	.62	24		24	212	54	7.2	3,960	4,190	5,750		5,770 (100)	6,510	
837	232	do	.62	24		48	212	53	6.6	4,360	4,670	4,860		4,620 (95)	4,770	
838	232	do	.62	24		96	212	51	6.1	4,330	4,990	5,030		4,210 (84)	5,190	
839	232	do	.62	24		192	212	47	6.1	5,180	6,050	5,130		4,550 (89)	5,060	

[1] Standard Ottawa sand cylinder.

[2] Minutes.

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TABLE 10.—*Tests of 2 by 4 inch concrete cylinders cured in water vapor at various temperatures and exposed to the action of sulphate water of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

TEMPERATURE, 212° F. (COMBINED IN SOME SERIES WITH 155° F.)—Continued

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Time in water	Time in water vapor	Temperature of water vapor	Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	28 days	1 year	5 years	Lake specimens: 1 year	3 years	5 years
				Hours	*Days*	*Hours*	*° F.*	*Days*	*Per cent*							
[1] 108	17	½A and ½B1	0.64	24		24 24	155 212	25	9.8	2,590	2,910	2,930	2,880	2,540 (87)	3,390	2,580 (90)
[1] 110	17	do	.64	24		48 24	155 212	24	9.5	2,600	3,160	2,940	2,590	2,720 (93)	3,160	2,360 (91)
[1] 111	17	do	.64	24		24 48	155 212	24	9.7	2,510	3,130	2,630	3,020	2,450 (93)	2,820	2,320 (77)
[1] 112	17	do	.64	24	27				10.0	1,650	2,630	3,540	2,790	1,790 (51)	0	0
[1] 113	17	do	.64	72				25	10.7	2,000	2,000	2,980	2,940	840 (28)	0	0
[1] 116	17	do	.64	24		48	212	25	10.3	2,220	2,470	2,500	3,250	2,430 (97)		2,460 (73)
[1] 128	17	do	.64	24		24 24	155 212	53	9.1	2,350	2,480	2,830	3,340	3,180 (112)		2,040 (61)
[1] 130	17	do	.64	24		48 24	155 212	52	9.1	2,750	2,720	2,830	3,130	3,080 (109)		1,740 (56)
[1] 131	17	do	.64	24		24 48	155 212	52	9.2	2,630	2,470	2,600	2,940	2,560 (98)		1,730 (59)

TEMPERATURE, 230° F. GAGE PRESSURE, 6.1 POUNDS PER SQUARE INCH

353	74	½A and ½B1	0.62	24		12	235	54	7.3	1,900	2,750	4,780	5,410	3,800 (79)	3,970	2,480 (46)
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
811	219	do	.62	24	20			35	5.5	3,620	4,930	6,350		0	0	0
812	219	do	.62	24		¾	230	55	7.0	2,060	2,170	5,530		5,160 (93)	5,120	
813	219	do	.62	24		1½	230	55	6.9	1,830	2,190	5,620		4,530 (81)	5,220	
814	219	do	.62	24		3	230	55	6.7	2,180	2,320	6,020		4,860 (81)	6,100	
815	219	do	.62	24		6	230	55	6.6	2,390	2,990	5,520		5,320 (96)	6,070	
820	222	do	.62	24		12	230	103	6.8	2,640	3,200	5,260		4,990 (95)	6,130	
821	222	do	.62	24		24	230	102	6.6	3,560	3,250	4,740		4,520 (95)	6,080	
829	225	do	.62	24		48	230	87	6.9	3,900	4,650	4,640		4,360 (94)	5,900	
855	232	do	.62	24	20			35	5.7	3,840	5,310	5,540		4,070 (73)	0	0
869	232	do	.62	24		96	230	46	6.1	4,480	4,600	4,480		4,600 (103)	5,330	
870	232	do	.62	24		192	230	42	6.2	3,830	4,450	3,360		3,560 (106)	4,470	

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TEMPERATURE, 260° F. GAGE PRESSURE, 20.7 POUNDS PER SQUARE INCH

354	74	½A and ½B1	0.62	24		12	260	54	7.1	2,270	2,490	4,880	5,570	3,760 (77)	4,160	3,320 (60)
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
806	219	do	.62	24	20			35	5.8	3,450	4,620	6,110		1,620 (27)	0	0
807	219	do	.62	24		¾	260	55	7.4	1,960	1,930	5,400		4,610 (85)	5,050	
808	219	do	.62	24		1½	260	55	7.1	2,000	2,130	5,490		4,990 (91)	5,360	
809	219	do	.62	24		3	260	55	7.2	2,170	2,460	5,090		5,200 (102)	5,540	
810	219	do	.62	24		6	260	55	7.0	2,790	2,870	5,380		4,940 (92)	5,750	
818	222	do	.62	24		12	260	97	6.7	3,190	3,380	5,560		4,630 (83)	5,840	
819	222	do	.62	24		24	260	95	6.7	3,480	3,810	4,620		4,520 (98)	5,290	
828	225	do	.62	24		48	260	83	6.6	3,720	3,880	3,990		3,790 (95)	4,760	
855	232	do	.62	24	20			35	5.7	3,840	5,310	5,540		4,070 (73)	0	0
867	232	do	.62	24		96	260	48	6.4	3,820	3,810	3,460		3,550 (103)	3,830	
868	232	do	.62	24		192	260	44	6.6	3,260	3,690	3,420		2,940 (86)	3,400	

TEMPERATURE, 285° F. GAGE PRESSURE, 38.5 POUNDS PER SQUARE INCH

355	74	½A and ½B1	0.62	24		12	285	54	7.2	2,260	2,870	4,340	5,250	3,870 (89)	3,970	4,190 (80)
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
430	97, 98	K1	.64	24		12	285	54	6.6	2,960	3,470	3,950	4,830	3,680 (93)	5,000	4,210 (87)
431	86, 99	I	.64	24		12	285	54	6.1	3,650	4,150	4,470	5,330	4,290 (96)	5,440	5,440 (102)
432	82, 95	C	.67	24		12	285	54	6.9	3,330	3,820	5,530	6,550	4,930 (89)	5,460	5,410 (83)
433	83	H	.64	24		12	285	54	6.5	3,460	3,950	5,110	6,520	4,840 (95)	5,510	5,980 (92)
801	219	½A and ½B1	.62	24	20			35	5.8	3,740	6,260	5,790		2,820 (49)	0	0
802	219	do	.62	24		¾	285	55	7.3	1,780	1,740	5,240		5,570 (106)	5,980	
803	219	do	.62	24		1½	285	55	7.2	2,010	2,220	6,550		5,560 (85)	5,980	
804	219	do	.62	24		3	285	55	7.3	2,420	2,590	5,560		5,650 (102)	5,700	
805	219	do	.62	24		6	285	55	6.8	3,080	3,370	5,860		5,600 (96)	6,720	
816	222	do	.62	24		12	285	87	6.5	3,320	3,420	4,940		4,510 (91)	5,350	
817	222	do	.62	24		24	285	85	6.3	3,740	4,160	4,540		4,750 (105)	4,790	
827	225	do	.62	24		48	285	64	6.7	3,300	3,600	3,200		3,170 (99)	4,060	
855	232	do	.62	24	20			35	5.7	3,840	5,310	5,540		4,070 (73)	0	0
865	232	do	.62	24		96	285	45	6.5	3,550	4,230	3,680		4,190 (118)	4,620	
866	232	do	.62	24		192	285	41	6.5	3,540	4,300	4,270		4,530 (106)	4,940	

TEMPERATURE, 315° F. GAGE PRESSURE, 68.7 POUNDS PER SQUARE INCH

840	232	½A and ½B1	0.62	24	20			35	5.8	3,810	5,050	6,010		3,060 (51)	0	0
841	232	do	.62	24		¾	315	55	6.9	2,010	2,020	5,680		5,130 (90)	5,740	
842	232	do	.62	24		1½	315	55	6.8	2,490	2,640	5,550		5,390 (97)	6,170	
843	232	do	.62	24		3	315	55	6.5	3,090	3,030	5,620		5,220 (93)	6,430	
844	232	do	.62	24		6	315	55	6.8	3,560	3,900	5,110		5,100 (100)	6,040	
845	232	do	.62	24		12	315	55	6.5	3,410	3,780	4,150		4,340 (105)	4,660	
846	232	do	.62	24		24	315	54	6.8	3,180	3,750	3,440		2,770 (81)	3,650	
847	232	do	.62	24		48	315	53	6.8	3,440	3,970	3,160		3,240 (103)	3,810	
848	232	do	.62	24		96	315	51	6.6	3,430	4,280	3,090		3,620 (117)	4,310	
849	232	do	.62	24		192	315	47	6.8	3,580	4,640	3,130		4,470 (143)	4,660	

[1] Standard Ottawa sand cylinders.

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TABLE 10.—*Tests of 2 by 4 inch concrete cylinders cured in water vapor at various temperatures and exposed to the action of sulphate water of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

TEMPERATURE, 350° F. GAGE PRESSURE, 119.8 POUNDS PER SQUARE INCH

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method					Absorption at 21 days	Average compression tests (pounds per square inch)						
										Tank specimens				Lake specimens		
				Time in moist closet	Time in water	Time in water vapor	Temperature of water vapor	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
				Hours	*Days*	*Hours*	*° F.*	*Days*	*Per cent*							
855	232	½A and ½B1	0.62	24	20	--------	--------	35	5.7	3,840	5,310	5,540	--------	4,070 (73)	0	0
856	232	do	.62	24	--------	¾	350	55	7.3	1,670	1,940	5,710	--------	4,790 (84)	5,750	--------
857	232	do	.62	24	--------	1½	350	55	7.0	2,500	2,800	5,950	--------	5,350 (90)	6,620	--------
858	232	do	.62	24	--------	3	350	55	6.7	3,210	3,310	5,610	--------	5,170 (92)	6,160	--------
859	232	do	.62	24	--------	6	350	55	6.8	3,110	3,540	4,300	--------	4,130 (96)	4,990	--------
860	232	do	.62	24	--------	12	350	55	6.7	3,280	3,470	3,880	--------	3,760 (97)	4,460	--------
861	232	do	.62	24	--------	24	350	54	6.8	3,830	3,840	4,700	--------	4,220 (90)	5,040	--------
862	232	do	.62	24	--------	48	350	53	6.5	3,530	4,710	4,580	--------	4,800 (105)	5,910	--------
863	232	do	.62	24	--------	96	350	51	6.3	4,140	4,320	4,670	--------	4,530 (97)	5,820	--------
864	232	do	.62	24	--------	192	350	47	6.2	3,770	4,260	5,000	--------	4,310 (86)	5,520	--------

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Curing in water vapor at temperatures ranging upward from 212° F. increases resistance to a remarkable degree. Full correlation of resistance, curing temperatures, and length of curing periods must await later results, but for tests between 212° and 285° F. resistance has been in the order of both temperature and length of curing period.

Curing in water vapor at temperatures between 100° and 190° F. does not increase resistance; on the contrary, in some cases decreased resistance follows. Exceptions to this occurred with cylinders containing certain admixtures as discussed on pages 59 to 74.

ABSORPTION AND STRENGTH

Those cylinders referred to in Table 10 that were cured continuously in water averaged lower in absorption than did the cylinders cured in water vapor. For identical curing periods, absorption was nearly constant, regardless of temperature, although there was a tendency for absorption to decrease as duration of the curing period increased.

The data in Tables 11, 12, and 13 do not indicate a general increase of strength of the fresh cements, with increase of temperatures above 100° F., with the single exception of those cylinders cured at 155°. On the other hand, those cylinders referred to in Table 11 that were made with the cements stored for one year, generally displayed a tendency to increase in strength as the curing temperature was increased. The 10 fresh cements used in these tests were purchased in the open market from warehouse stocks newly received, as indicated by invoices, while the stored cements were lots of the same brands that had been kept in their original bags in a winter-heated dry room and were not lumpy when tested.

TABLE 11.—*Compression strength of concrete cylinders cured in water vapor at temperatures between 100° and 350° F. for different periods*

[All cylinders were first cured 24 hours at room temperature in moist closet. Cylinders cured in water vapor were stored in air and tested dry in compression at seven days. Test results are, in all cases, the average for four or more cylinders. Italicized figures indicate retrogression in strength]

MADE WITH FRESH CEMENT

Series	Portland cement	Check cylinders cured in water			Compression tests at 7 days, pounds per square inch				
		Absorption (per cent) at 21 days	Compression tests, pounds per square inch		Cylinders cured in water vapor at 100° F.				
			7 days	28 days	1½ hours	6 hours	24 hours	96 hours	Average for 1½–96 hours
274	I	5.9	4,240	5,500	3,360	3,970	4,390	5,810	4,380
275	K1	5.8	4,010	6,340	3,550	3,770	4,730	*4,540*	4,150
276	H	6.1	3,680	5,210	3,110	3,450	3,930	4,610	3,780
277	C	6.2	3,640	5,620	2,610	3,190	3,800	4,170	3,440
278	E	5.9	3,560	5,700	2,900	2,900	3,670	4,110	3,400
279	F	5.5	5,110	6,700	3,750	4,090	5,370	*5,040*	4,560
280	G	6.2	4,240	5,270	2,980	3,800	4,260	4,280	3,830
281	M	5.8	4,040	5,270	3,310	3,810	4,280	4,680	4,020
282	P	5.5	4,420	6,590	3,510	3,830	4,730	*4,470*	4,140
284	D	5.5	4,470	6,050	3,670	4,150	4,990	6,090	4,730
Average		5.8	4,140	5,830	3,280	3,700	4,420	4,780	4,040

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TABLE 11.—*Compression strength of concrete cylinders cured in water vapor at temperatures between 100° and 350° F. for different periods*—Continued

MADE WITH CEMENT STORED FOR ONE YEAR

Series	Portland cement	Check cylinders cured in water			Compression tests at 7 days, pounds per square inch				
		Absorption (per cent) at 21 days	Comprersion tests, pounds per square inch		Cylinders cured in water vapor at 100° F.				
			7 days	28 days	1½ hours	6 hours	24 hours	96 hours	Average for 1½–96 hours
206	I	6.1	2,560	5,200	600	2,370	*2,130*	3,480	2,140
207	K1	6.5	2,560	4,510	980	1,870	2,260	2,820	1,980
208	H	6.5	2,910	4,620	1,940	2,010	3,150	*3,000*	2,520
209	C	6.8	2,140	4,520	830	1,310	2,280	*2,140*	1,640
210	E	6.3	3,430	4,890	1,970	2,980	3,420	3,900	3,070
211	F	6.2	3,590	4,900	2,450	*2,420*	3,840	3,890	3,150
212	G	6.3	2,930	4,740	1,870	2,260	3,250	3,560	2,730
213	M	6.6	2,760	4,510	2,120	*2,080*	3,210	3,430	2,710
215	P	6.1	3,860	4,670	2,880	2,990	4,160	*3,730*	3,440
217	D	6.3	3,360	5,220	1,690	2,290	3,180	3,880	2,760
Average		6.4	3,010	4,780	1,730	2,260	3,090	3,380	2,610

MADE WITH FRESH CEMENT

Series	Portland cement	Compression tests at 7 days, pounds per square inch									
		Cylinders cured in water vapor at 155° F.					Cylinders cured in steam at 212° F.				
		1½ hours	6 hours	24 hours	96 hours	[1]Average for 1½–96 hours	1½ hours	6 hours	24 hours	96 hours	Average for 1½–96 hours
274	I	4,200	4,560	*4,090*	5,480	4,580	3,780	3,790	4,410	4,740	4,180
275	K1	3,920	*3,700*	4,610	*4,460*	4,170	3,310	3,410	4,440	*4,100*	3,820
276	H	3,710	4,490	4,770	5,690	4,670	2,520	3,080	3,160	4,290	3,260
277	C	3,020	3,710	4,490	5,350	4,140	2,580	3,050	3,940	5,190	3,690
278	E	3,240	3,930	4,790	5,550	4,380	2,740	*2,680*	4,230	4,590	3,560
279	F	4,330	5,370	*5,200*	5,850	5,190	3,790	4,050	*4,020*	5,130	4,250
280	G	3,550	4,160	5,130	5,740	4,650	2,840	3,510	3,950	4,370	3,670
281	M	3,480	4,610	*4,410*	5,660	4,540	3,170	*3,000*	4,430	4,680	3,820
282	P	3,570	4,820	*4,530*	5,650	4,640	3,770	3,860	4,180	5,620	4,360
284	D	3,860	4,960	6,070	6,420	5,330	3,800	4,000	4,610	5,530	4,490
Average		3,690	4,430	4,810	5,590	4,630	3,230	3,440	4,140	4,820	3,910

MADE WITH CEMENT STORED FOR ONE YEAR

206	I	------	------	------	------	------	1,530	*1,470*	2,290	2,850	2,030
207	K1	1,220	1,800	2,310	3,700	2,260	2,120	*1,520*	2,320	3,420	2,340
208	H	1,940	2,140	2,990	3,770	2,710	1,700	1,950	2,560	4,360	2,640
209	C	------	------	------	------	------	1,200	1,610	2,100	3,930	2,210
210	E	2,500	3,090	3,600	4,160	3,340	1,860	2,090	2,760	4,380	2,770
211	F	2,130	2,470	3,080	4,870	3,140	2,070	2,520	3,340	4,610	3,130
212	G	------	------	------	------	------	1,600	2,200	2,870	3,780	2,610
213	M	2,310	2,530	3,120	4,120	3,020	1,580	1,980	2,480	4,590	2,660
215	P	------	------	------	------	------	2,270	2,850	3,750	4,830	3,420
217	D	1,850	2,230	3,520	4,230	2,960	2,120	2,690	2,920	3,650	2,840
Average		[1]1,990	[1]2,380	[1]3,100	[1]4,140	[1]2,900	1,800	2,090	2,740	4,030	2,660

[1] Averages for 6 cements only.

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TABLE 11.—*Compression strength of concrete cylinders cured in water vapor at temperatures between 100° and 350° F. for different periods*—Continued

MADE WITH FRESH CEMENT

Series	Portland cement	Compression tests at 7 days, pounds per square inch							
		Cylinders cured in steam at 260° F.					Cylinders cured in steam at 315° F.		
		1½ hours	6 hours	24 hours	96 hours	Average for 1½–96 hours	1½ hours	6 hours	24 hours
274	I	3,160	3,630	4,010	*3,630*	3,610	2,970	4,070	*3,240*
275	K1	2,710	3,040	4,550	*3,830*	3,530	2,860	3,840	*3,300*
276	H	2,450	2,820	3,440	3,780	3,120	2,290	3,430	4,270
277	C	2,260	2,680	4,240	4,760	3,490	2,220	3,590	3,960
278	E	2,390	2,970	4,090	4,440	3,470	2,160	4,030	4,950
279	F	3,470	4,120	5,310	*4,330*	4,310	3,320	4,230	*4,100*
280	G	2,760	2,920	4,260	*2,050*	3,000	2,710	*2,400*	2,820
281	M	2,340	2,840	3,770	5,240	3,550	2,650	3,760	4,470
282	P	3,040	3,940	5,330	*4,750*	4,270	3,050	4,170	4,540
284	D	3,180	4,120	4,890	*3,660*	3,960	3,250	4,190	*3,010*
Average		2,780	3,310	4,390	*4,050*	3,630	2,750	3,770	3,870

MADE WITH CEMENT STORED FOR ONE YEAR

206	I	1,180	1,370	2,570	2,930	2,010	830	1,990	3,080
207	K1	1,290	2,100	2,910	4,040	2,580	1,140	2,480	3,940
208	H	1,520	2,260	3,300	4,070	2,790	1,710	2,650	4,810
209	C	1,230	2,130	3,220	3,800	2,590	1,160	2,390	3,860
210	E	1,340	2,250	3,770	4,900	3,060	1,610	2,910	4,120
211	F	1,950	2,610	3,660	5,540	3,440	1,830	3,470	5,450
212	G	1,930	2,510	3,730	*2,950*	2,780	1,700	2,990	3,620
213	M	1,260	2,120	3,350	4,610	2,830	1,750	2,730	4,870
215	P	2,470	2,980	4,250	5,070	3,690	1,600	3,360	*3,080*
217	D	1,520	2,080	3,100	*3,040*	2,410	1,980	2,420	4,170
Average		1,570	2,240	3,390	4,090	2,820	1,530	2,740	4,100

MADE WITH FRESH CEMENT

Series	Portland cement	Compression tests at 7 days, pounds per square inch						
		Cylinders cured in steam at 315° F.		Cylinders cured in steam at 350° F.				
		96 hours	Average for 1½–96 hours	1½ hours	6 hours	24 hours	96 hours	Average for 1½–96 hours
274	I	3,460	3,440	3,150	3,520	4,610	4,610	3,970
275	K1	3,590	3,400	2,910	3,600	3,780	4,720	3,750
276	H	*3,710*	3,430	2,060	4,320	4,570	*4,180*	3,780
277	C	*3,860*	3,410	2,200	3,880	4,340	4,860	3,820
278	E	*4,910*	4,010	2,100	4,460	5,330	*4,410*	4,080
279	F	4,430	4,020	3,200	4,230	4,850	6,230	4,630
280	G	3,750	2,920	2,660	2,970	4,110	4,850	3,650
281	M	*4,070*	3,740	2,870	4,180	4,490	5,170	4,180
282	P	4,900	4,170	3,020	4,040	4,930	5,630	4,410
284	D	*2,780*	3,310	3,110	3,310	4,330	4,520	3,820
Average		3,950	3,590	2,730	3,850	4,530	4,920	4,010

MADE WITH CEMENT STORED FOR ONE YEAR

206	I	*2,960*	2,210	1,250	2,540	3,020	4,200	2,750
207	K1	*3,760*	2,830	1,450	2,910	4,110	4,320	3,200
208	H	*4,560*	3,430	1,730	2,850	4,790	*3,940*	3,330
209	C	4,050	2,860	1,460	2,520	3,760	3,800	2,880
210	E	4,980	3,400	1,440	2,860	4,880	*4,090*	3,320
211	F	*5,320*	4,020	1,340	3,470	5,090	*4,360*	3,560
212	G	4,310	3,150	2,070	2,820	4,050	5,340	3,570
213	M	*4,510*	3,460	1,480	2,810	4,390	4,530	3,300
215	P	4,990	3,260	2,680	3,340	4,710	4,710	3,860
217	D	*2,700*	2,820	2,040	2,600	3,370	4,260	3,070
Average		4,210	3,140	1,690	2,870	4,220	4,350	3,280

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TABLE 12.—*Compressive strength per square inch and absorption in 21 days of concrete cylinders cured in water vapor for periods of three-fourths of an hour to 8 days at various temperatures*

[All cylinders were first cured 24 hours in moist closet at room temperatures, and following curing in water vapor were stored in dry air until tested. Each test result is average for 4 or more cylinders. Cement used was equal parts brands A and B1]

Temperature of water vapor	Check cylinders cured in water			¾ hour			1½ hours	
	Absorption	Compression		Absorption	Compression		Compression	
		7 days	28 days		7 days	28 days	7 days	28 days
°F	*Per cent*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100	----------	3,270	----------	----------	2,630	----------	2,460	----------
155	----------	3,550	----------	----------	2,940	----------	3,240	----------
212	5.9	3,230	4,720	6.9	3,020	2,880	2,590	2,400
230	5.6	3,730	5,100	7.0	2,060	2,170	1,830	2,190
260	5.8	3,640	4,960	7.4	1,960	1,930	2,000	2,130
285	5.8	3,790	5,780	7.3	1,780	1,740	2,010	2,220
315	5.8	3,810	5,050	6.9	2,010	2,020	2,490	2,640
350	5.7	3,840	5,310	7.3	1,670	1,940	2,500	2,800
Average	5.8	3,670	5,150	7.1	2,080	2,110	2,240	2,400

Temperature of water vapor	1½ hours	3 hours			6 hours		
	Absorption	Absorption	Compression		Absorption	Compression	
			7 days	28 days		7 days	28 days
°F.	*Per cent*	*Per cent*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*
100	----------	----------	3,080	----------	----------	3,290	----------
155	----------	----------	3,380	----------	----------	3,730	----------
212	7.4	7.2	2,890	3,130	7.0	3,220	3,470
230	6.9	6.7	2,180	2,320	6.6	2,390	2,990
260	7.1	7.2	2,170	2,460	7.0	2,790	2,870
285	7.2	7.3	2,420	2,590	6.8	3,080	3,370
315	6.8	6.5	3,090	3,030	6.8	3,560	3,900
350	7.0	6.7	3,210	3,310	6.8	3,110	3,540
Average	7.1	6.9	2,660	2,810	6.8	3,030	3,360

Temperature of water vapor	12 hours			24 hours			2 days	
	Absorption	Compression		Absorption	Compression		Compression	
		7 days	28 days		7 days	28 days	7 days	28 days
°F.	*Per cent*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100	----------	3,470	----------	----------	4,280	----------	4,220	----------
155	----------	4,020	----------	----------	4,420	----------	4,460	----------
212	7.1	3,570	3,580	7.2	3,960	4,190	4,360	4,670
230	6.8	2,640	3,200	6.6	3,560	3,250	3,900	4,650
260	6.7	3,190	3,380	6.7	3,480	3,810	3,720	3,880
285	6.5	3,320	3,420	6.3	3,740	4,160	3,300	3,600
315	6.5	3,410	3,780	6.8	3,180	3,750	3,440	3,970
350	6.7	3,280	3,470	6.8	3,830	3,840	3,530	4,710
Average	6.7	3,340	3,470	6.7	3,630	3,830	3,710	4,250

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TABLE 12.—*Compressive strength per square inch and absorption in 21 days of concrete cylinders cured in water vapor for periods of three-fourths of an hour to 8 days at various temperatures*—Continued

Temperature of water vapor	2 days	4 days			8 days		
	Absorption	Absorption	Compression		Absorption	Compression	
			7 days	28 days		9 days	28 days
°F.	*Per cent*	*Per cent*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*
100			4,870			5,280	
155			4,720			4,820	
212	6.6	6.1	4,330	4,990	6.1	5,180	6,050
230	6.9	6.1	4,480	4,600	6.2	3,830	4,450
260	6.6	6.4	3,820	3,810	6.6	3,260	3,690
285	6.7	6.5	3,740	4,230	6.5	3,540	4,300
315	6.8	6.6	3,430	4,280	6.8	3,580	4,640
350	6.5	6.3	4,140.	4,320	6.2	3,770	4,260
Average	6.7	6.3	3,990	4,370	6.4	3,860	4,570

TABLE 13.—*Compressive strength in pounds per square inch of concrete cylinders cured for 12 to 32 days in water vapor at different temperatures*

Temperature of water vapor	12 days	14 days	16 days	18 days	20 days	22 days	24 days	26 days	28 days	30 days	32 days
100° F	4,760	4,910	4,610	4,760	4,460	4,290	5,380	4,950	5,100	4,610	4,530
155° F	5,190	4,690	5,210	4,590	4,740	4,850	5,000	4,730	5,020	4,960	4,550
212° F	4,670	4,550	5,080	4,580	4,530	4,840	4,430	4,600	4,290	4,500	4,860
Average	4,870	4,720	4,970	4,640	4,580	4,660	4,940	4,760	4,800	4,690	4,650

From a comparison of Figures 12 and 13, it is evident that the strength tests were more uniformly consistent, although lower, for the stored cements than for the fresh cements, with the closest agreement in actual strengths for curing temperatures of 260°, 315°, and 350° F., for the 24 and 96 hour curing periods. While strengths of the steam-cured cylinders averaged lower than 28-day strengths of the water-cured check cylinders, the data in Tables 11 to 13 reveal that individually, in some one or more of the high temperatures, cylinders made of each of the cements either exceeded or approached the 28-day strengths of comparable water-cured ones. There was not, however, any tendency for the steam-cured cylinders to develop abnormally high compressive strengths.

These strength trends are somewhat contrary to those reported a number of years ago by Wig (*53*), whose report was based on tests made in 1907 and 1908 in the structural materials laboratory of the United States Geological Survey at St. Louis, Mo., in which it was found that:

> A compressive strength considerably (in some cases over 100 per cent) in excess of that obtained normally after aging for six months may be obtained in two days by using steam under pressure for curing the mortar or concrete.

Woodworth (*60*) in 1930 and Pearson and Brickett (*41*) in 1932 published reports that substantiated these conclusions of Wig.

It is possible that the strength of steam-cured concrete is influenced by both the cement and the sand, since in the manufacture of sand-lime brick strengths upward of 8,500 pounds per square inch have

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been obtained by using steam pressures of 125 to 150 pounds per square inch (*42*). It is evident, therefore, that Portland-cement concrete cured at these high temperatures could reasonably be expected to be stronger than that normally cured, particularly at less ages, if conditions were such that the free lime hydrate of the cement could combine readily with the silica of the sand which is active at these high temperatures. That some concretes cured at high temperatures do not develop strengths in excess of the strength of concrete cured normally may indicate that the active silica in the sand is not sufficient to bring this about.

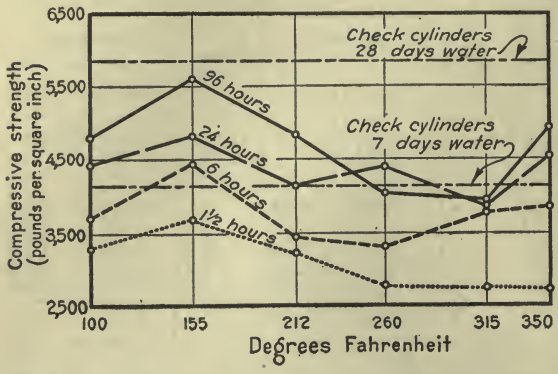

FIGURE 12.—Strength, at 7 days, of concrete cylinders made of fresh cements cured in water vapor at temperatures shown for 1½ to 96 hours. (Based on Table 11)

Cylinders of all the cements, both fresh and stored, showed retrogression of strength for some time period at some of the temperatures, particularly for the 4-day (96 hours) period at temperatures of 260° and 315° F. Such retrogression was generally followed by full recovery of strength in tests at higher temperatures. Retrogression of the strength of cement steam cured under different conditions has been observed by a number of other workers. (*9, 48, 56, 60.*) The following explanation of this phenomenon has been suggested by Thorvaldson and Vigfusson (*48*) as a result of an interesting series of physical and chemical experiments at the University of Saskatchewan under the auspices of a research committee of the Engineering Institute of Canada.

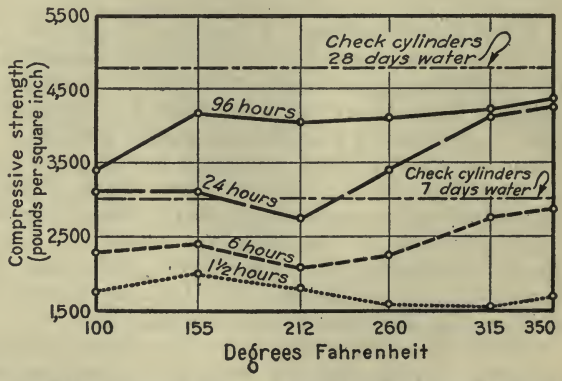

FIGURE 13.—Strength, at 7 days, of concrete cylinders, made of cements stored for 1 year, cured in water vapor at temperatures shown for 1½ to 96 hours. (Based on Table 11)

It seems probable that the first action, causing a loss in tensile strength, is due to a change in the tricalcium aluminate of the cement and that this change is the primary cause of the increase in the sulphate resistance of the mortar. The second change, causing an increase in tensile strength, could then probably be due to hydration of the silicates, speeded up by the action of steam or possibly partly due to the formation of stable cementing substances from the aluminate.

Regardless of whatever physical or chemical changes in Portland cement follow curing in water vapor at temperatures of 212° F. and upward, hydration of the cement grains is very greatly accelerated. This is well shown in Plate 4 by the photomicrographs of thin sections

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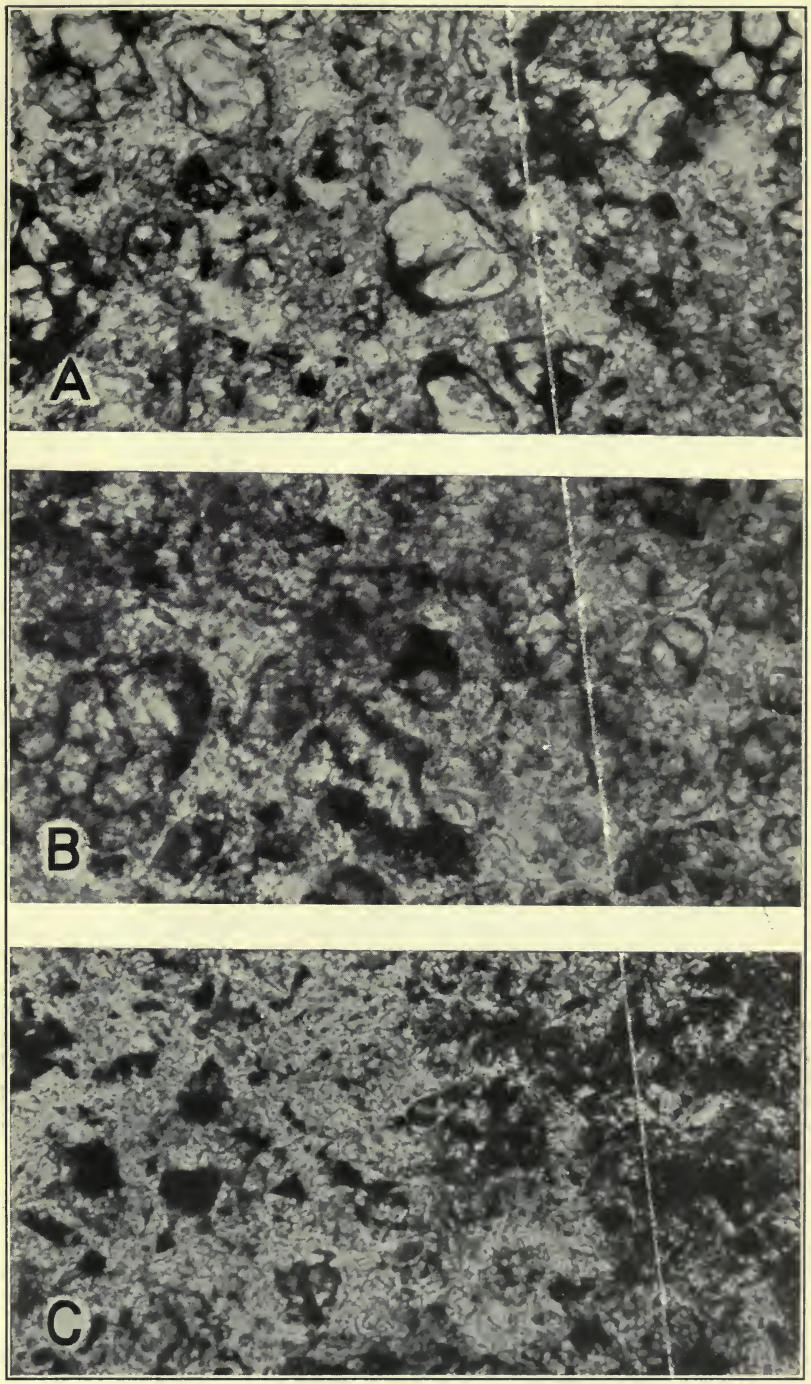

PHOTOMICROGRAPHS OF NEAT CEMENT BRIQUETS SHOWING PHYSICAL CHANGES RESULTING FROM DIFFERENT CONDITIONS OF CURING

A, Cured 12 days in water at room temperatures. B, Cured 6 hours in steam at 315° F. C, Cured 24 hours in steam at 315°. (× 350)

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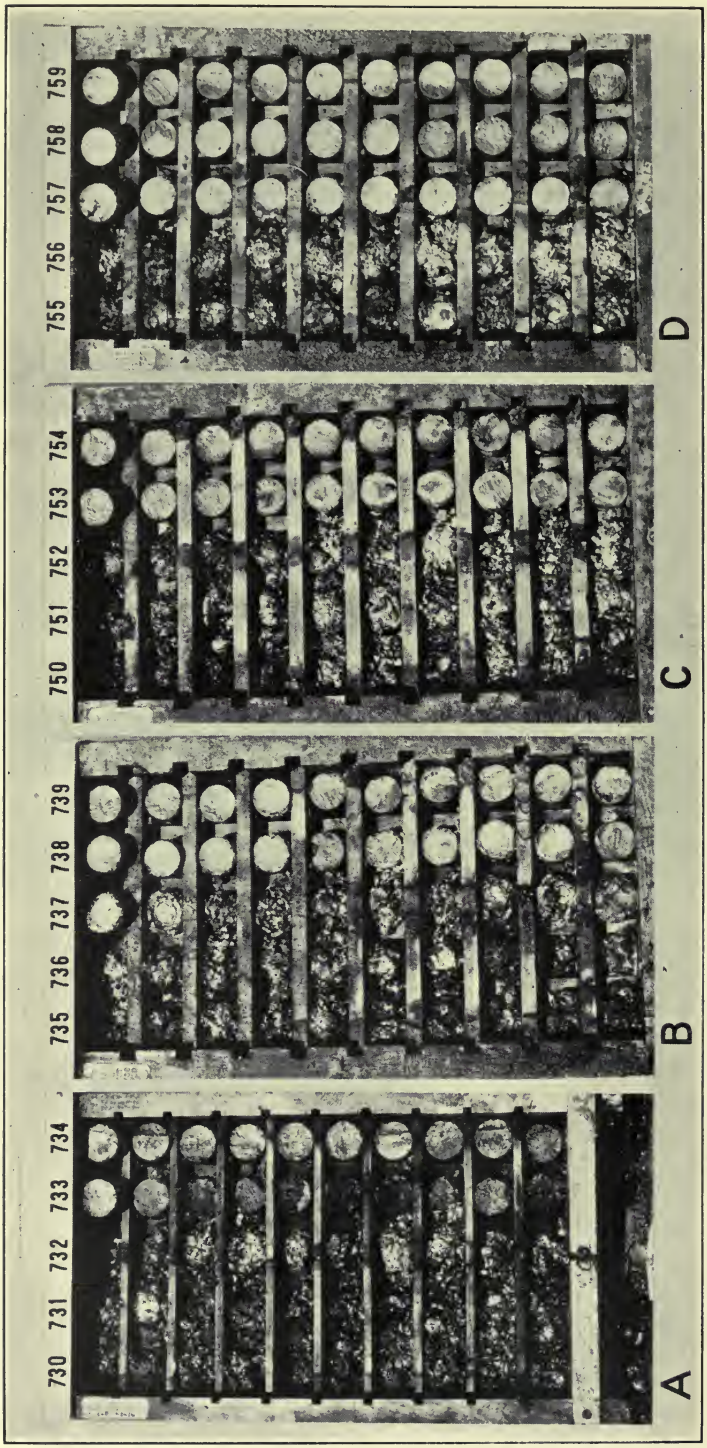

CYLINDERS MADE OF TWO DIFFERENT LOTS OF STANDARD PORTLAND CEMENT AFTER STORAGE IN MEDICINE LAKE FOR THREE YEARS

From left to right the cements in each group are B1, A, D, G and I. A, Without air hardening. B, Air hardening five weeks. C, Without air hardening. D, Air hardening five weeks

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of specimens. Within a few hours the steam-cured cement grains are greatly altered and reduced in size to a degree not approached in the water-cured specimens after 12 days.

Concrete cured in water vapor at all temperatures up to 350° F. and then stored in water, ordinarily gains strength much as it does when water-cured, although the rate of gain is somewhat retarded, the retardation depending on temperatures and duration of curing period. This statement is based on a study of the 7 and 28 day and 1 and 5 year test data in Table 10.

The effect on the 28-day strength of concrete, of applying water vapor at temperatures of 100°, 155°, and 212° F., at early ages, is illustrated in Figure 14. These graphs indicate that curing of concrete at temperatures above normal should preferably be commenced 12 to 24 hours after the concrete is made. Figure 14 is based on tests of cylinders made in 1923, entirely unrelated to those referred to in Figures 12 and 13, yet the cylinders cured at 155° were stronger in all cases than those cured at either 100° or 212°.

All temperatures in these steam-curing tests were those to which specimens were actually subjected during curing and, it will be noted, are considerably above those of 100° to 135° F. ordinarily used at commercial tile plants manufacturing "steam-cured" products. The maximum temperature of 350° is no greater, however, than has been used in the manufacture of sand-lime brick, and is therefore within the limit of practical application. A previous publication (*37*) gives more complete details about certain phases of concrete cured at high temperatures.

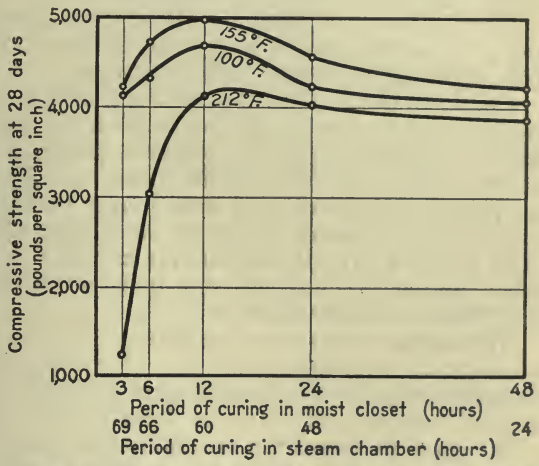

FIGURE 14.—Strength of concrete cylinders as affected by the time of their transfer from moist closet to steam chamber. The total curing period of 72 hours was followed by 25 days in air. Each point is the average for five cylinders made on different days and tested room-dry. (Cements A and B1 mixed in equal portions)

RESULTS WITH VAPOR-CURED CONCRETE

Concrete cured 12 to 24 hours in water vapor at temperatures between 100° and 350° F., then stored in dry air at room temperatures, had a compressive strength at seven days not greatly different from that of 7-day concrete water cured at room temperatures.

Curing prolonged beyond 48 hours had little effect on compressive strength of concrete cured in water vapor at temperatures between 190° and 350° F. Concrete cured 48 hours at these temperatures ordinarily attained a maximum and fairly constant strength equal to 80 to 90 per cent of that of 28-day concrete continuously water cured at room temperatures.

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Variations in curing temperatures between the limits of 100° and 350° F. had no pronounced effect on strength, although specimens made with fresh cements were consistently somewhat stronger when cured at 155° than at the other temperatures. Specimens made of cements stored one year gave more uniform results but had lower strengths than those made of fresh cements. These statements are based on curing periods up to 8 days for all temperatures and up to 32 days for temperatures of 100°, 155°, and 212°. (Tables 12 and 13.)

With some exceptions, cylinders stored in tap water in the laboratory after being cured in high-temperature water vapor continued to increase in strength at a rate not essentially different from that of water-cured check cylinders.

To obtain the highest compressive strength of the concrete, the most favorable time for applying water vapor at temperatures of 100°, 155°, and 212° F. was 12 to 24 hours after making. Data for the other temperatures are not available.

The reactions of concrete made of Portland cements from different mills to curing under these special conditions has been essentially similar in both strength and resistance.

Concrete made of all the cements used in the strength tests showed retrogression of strength for some time period after being cured in water vapor at some temperature between 100° and 350° F. The retrogression was followed in most cases by full recovery of strength at higher temperatures or after longer curing periods. This phenomenon occurred most frequently and generally was of greatest magnitude in those groups of cylinders cured 96 hours at 260° and 315° F., with the result that tests were more uniform at 100°, 155°, 212°, and 350° than at either 260° or 315°.

With some exceptions the cements that lost most in strength during storage, as indicated by tests of cylinders following curing at all temperatures for the shorter time periods, were the cements that displayed greatest resistance to deterioration in Medicine Lake.

No gain in resistance to alkali followed when the temperature of the water vapor in which the concrete was cured was increased until 212° F. was reached. Between 212° and 285°, increased resistance followed increase of curing temperature. At a temperature of 212°, increased resistance followed lengthening of the curing period up to six days. Data for longer curing periods and for other temperatures are yet too incomplete to be conclusive although, up to 1932, specimens cured at the highest temperatures and for the longest periods have made the most favorable showings.

Absorption of concrete cured in water vapor at high temperatures is not a criterion of resistance to sulphate waters.

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TABLE 14.—*Tests of 2 by 4 inch concrete cylinders made from Portland cements from different mills after exposure for various periods in Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions, is an average of 5 cylinders made on different days. Figures in parentheses, in compression test columns, indicate per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water in the laboratory]

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method			Absorption at 21 days	Average compression tests (pounds per square inch)						
								Tank specimens				Lake specimens		
				Time in moist closet	Time in water	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
				Hours	*Days*	*Days*	*Per cent*							
172	18	½A and ½B1	0.59	24	20	35	5.6	2,870	4,190	5,300	5,400	4,370 (82)	----------	0
177	18	do	.59	24	20	35	5.9	2,520	4,200	4,930	6,120	3,670 (74)	----------	0
256	61	do	.59	24	20	35	5.8	2,780	3,950	5,200	6,520	1,480 (28)	0	0
391	74	do	.62	24	20	35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
434	74	do	.66	24	20	35	6.4	2,590	4,030	5,050	5,830	4,870 (96)	0	0
554	129	do	.64	24	20	35	6.3	3,570	4,760	5,980	6,820	3,530 (59)	0	0
583	139	do	.62	24	20	35	6.3	3,810	4,950	6,420	7,820	3,650 (57)	0	0
640	139	do	.64	24	20	35	6.5	3,320	4,470	5,800	6,070	4,530 (78)	0	0
715	176	do	.62	24	20	35	5.6	3,830	5,100	6,420	----------	4,550 (71)	0	0
771	204	do	.62	24	20	35	5.9	3,450	4,440	5,870	----------	0	0	0
776	204	do	.62	24	20	35	6.2	3,400	4,420	6,480	----------	0	0	0
801	219	do	.62	24	20	35	5.8	3,740	6,260	5,790	----------	2,820 (49)	0	0
806	219	do	.62	24	20	35	5.8	3,450	4,620	6,110	----------	1,620 (27)	0	0
811	219	do	.62	24	20	35	5.5	3,620	4,930	6,350	----------	0	0	0
822	225	do	.62	24	20	35	5.3	3,220	5,230	6,250	----------	3,800 (61)	0	0
830	232	do	.62	24	20	35	5.9	3,230	4,720	6,360	----------	3,950 (62)	0	0
840	232	do	.62	24	20	35	5.8	3,810	5,050	6,010	----------	3,060 (51)	0	0
855	232	do	.62	24	20	35	5.7	3,840	5,310	5,540	----------	4,070 (73)	0	0
976	237	do	.62	24	20	35	6.0	3,700	4,590	5,750	----------	4,650 (81)	0	0
258	62	B1	.59	24	20	35	5.8	2,960	3,790	4,580	5,780	800 (17)	0	0
655	156	B1	.62	24	20	35	6.4	3,670	5,070	5,800	----------	2,870 (50)	0	0
665	156	B1	.62	24	20	----------	5.9	3,500	5,020	5,820	----------	3,860 (66)	0	0
670	161	B1	.62	24	20	----------	6.2	3,550	5,470	7,100	----------	3,050 (43)	0	0
675	161	B1	.62	24	20	35	5.8	3,490	5,320	6,450	----------	3,870 (60)	0	0
690	166	B1	.62	24	20	----------	6.4	2,830	4,580	6,150	----------	3,810 (62)	0	0
695	166	B1	.62	24	20	35	6.8	2,960	4,340	6,510	----------	4,210 (65)	0	0
699	170	B1	.62	24	20	35	5.8	3,660	5,580	6,250	----------	3,130 (50)	0	0
709	170	B1	.62	24	20	----------	5.8	4,020	4,910	6,940	----------	2,930 (42)	0	0
730	178	B1	.62	24	20	----------	5.6	3,400	4,610	5,780	----------	2,580 (45)	0	0
735	178	B1	.62	24	20	35	5.6	3,820	4,660	5,450	----------	5,360 (98)	0	0
750	183	B1	.62	24	20	----------	5.9	3,810	5,340	5,740	----------	1,790 (31)	0	0
755	183	B1	.62	24	20	35	5.7	3,500	5,190	5,650	----------	5,430 (96)	0	0

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TABLE 14.—*Tests of 2 by 4 inch concrete cylinders made from Portland cements from different mills after exposure for various periods in Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

Series	Cement laboratory No.	Portland cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hours	*Days*	*Days*	*Per cent*							
464	109	Portland B2	0.64	24	20	35	5.8	3,740	5,010	7,070	5,940	5,950 (84)	920	0
465	110	do	.64	24	20	35	5.5	3,660	4,920	6,910	6,070	4,850 (70)	0	0
466	111	Portland B3	.64	24	20	35	5.7	3,810	5,020	5,860	5,790	3,960 (68)	0	0
257	63	A	.59	24	20	35	5.8	2,720	4,290	5,490	6,440	3,190 (58)	0	0
657	158	A	.62	24	20	35	6.5	4,080	4,560	4,920	----------	0	0	0
667	158	A	.62	24	20	----------	6.0	3,450	4,570	6,280	----------	790 (13)	0	0
672	163	A	.62	24	20	----------	6.0	3,790	5,240	6,070	----------	1,880 (31)	0	0
677	163	A	.62	24	20	35	5.9	3,670	4,460	6,070	----------	1,630 (27)	0	0
692	168	A	.62	24	20	----------	5.6	3,760	5,520	5,760	----------	680 (12)	0	0
697	168	A	.62	24	20	35	5.9	3,970	5,440	5,820	----------	1,670 (29)	0	0
700	171	A	.62	24	20	35	5.8	3,950	5,360	6,190	----------	1,830 (30)	0	0
710	171	A	.62	24	20	----------	5.6	4,090	4,700	5,260	----------	1,940 (37)	0	0
731	179	A	.62	24	20	----------	5.7	3,500	4,770	6,430	----------	810 (13)	0	0
736	179	A	.62	24	20	35	5.8	3,680	5,030	5,080	----------	2,620 (52)	0	0
751	184	A	.62	24	20	----------	5.8	4,200	5,580	6,090	----------	2,310 (38)	0	0
756	184	A	.62	24	20	34	5.7	3,830	5,140	5,850	----------	4,420 (76)	0	0
369	86, 99	I	.64	24	20	35	6.1	3,590	4,370	6,110	6,650	4,470 (73)	2,500	0
703	174	I	.62	24	20	35	6.2	4,480	5,610	7,040	----------	6,240 (89)	4,150	----------
713	174	I	.62	24	20	----------	5.7	4,370	4,790	6,330	----------	5,800 (92)	5,600	----------
734	182	I	.62	24	20	----------	6.0	4,040	5,580	5,940	----------	6,230 (105)	6,740	----------
739	182	I	.62	24	20	35	5.8	3,620	5,260	5,810	----------	6,930 (119)	6,180	----------
754	187	I	.62	24	20	----------	6.2	3,980	5,050	6,770	----------	5,950 (88)	6,130	----------
759	187	I	.62	24	20	35	5.7	3,840	5,380	6,210	----------	6,040 (97)	6,810	----------
761	199	I	.62	24	20	35	6.0	4,160	4,830	7,560	----------	6,900 (91)	5,370	----------
372	97	K2	.64	24	20	35	6.4	3,120	4,440	5,720	7,350	4,600 (80)	2,260	1,450 (20)
658	159	K2	.62	24	20	35	6.5	3,990	5,170	6,290	----------	5,490 (87)	1,740	----------
668	159	K2	.62	24	20	----------	6.0	3,140	5,240	5,980	----------	5,790 (97)	4,410	----------
673	164	K2	.62	24	20	----------	6.0	4,260	5,340	6,800	----------	5,830 (86)	2,690	----------
678	164	K2	.62	24	20	35	5.9	3,770	5,580	6,270	----------	5,640 (90)	2,710	----------
693	169	K2	.62	24	20	----------	6.2	3,280	5,370	5,740	----------	5,460 (95)	5,060	----------
698	169	K2	.62	24	20	35	6.2	3,400	4,730	6,350	----------	6,580 (104)	4,610	----------
373	98	K1	.64	24	20	35	6.1	4,220	4,970	7,050	6,520	3,400 (48)	0	0
364	81	E	.62	24	20	35	5.8	3,340	4,770	7,320	7,540	2,910 (40)	0	0
404	103	S	.62	24	20	35	6.0	3,010	4,380	5,470	6,310	3,160 (58)	1,230	0
413	105	Q2	.62	24	20	35	5.7	3,520	5,390	6,500	6,350	4,300 (66)	0	0
401	100	Q1	.62	24	20	35	6.4	2,900	5,310	5,110	5,960	0 0	0	0
370	87, 88	P	.64	24	20	35	6.1	3,730	5,040	6,540	6,700	810 (12)	0	0

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371	84	L1	.64	24	20	35	5.8	3,690	5,000	5,770	6,230	3,170 (55)	250	0
260	34	C	.66	24	20	35	6.1	3,340	4,540	5,980	6,850	5,090 (85)	4,390	4,290 (63)
367	82,95	C	.67	24	20	35	6.8	3,220	4,320	6,270	7,760	4,790 (76)	2,280	0
654	155	C	.66	24	20	35	6.6	3,580	5,150	6,220	----------	5,910 (95)	3,260	----------
664	155	C	.66	24	20	----------	6.5	3,220	4,890	6,590	----------	6,250 (95)	4,820	----------
669	160	C	.66	24	20	----------	6.8	3,150	5,180	5,900	----------	6,190 (105)	5,120	----------
674	160	C	.66	24	20	35	6.5	3,430	5,480	7,030	----------	5,610 (80)	5,820	----------
689	165	C	.66	24	20	----------	6.3	3,200	5,600	7,390	----------	5,670 (77)	4,960	----------
694	165	C	.66	24	20	35	6.5	3,480	5,520	6,780	----------	5,910 (87)	4,400	----------
365	83	H	.62	24	20	35	6.1	3,940	4,770	6,280	7,250	3,680 (59)	290	0
656	157	H	.62	24	20	35	6.5	3,230	5,090	5,670	----------	4,510 (80)	0	0
666	157	H	.62	24	20	----------	6.0	3,520	5,120	6,640	----------	5,490 (83)	0	0
671	162	H	.62	24	20	----------	6.7	3,380	4,690	6,260	----------	5,550 (89)	4,140	----------
676	162	H	.62	24	20	35	6.5	3,330	4,490	5,830	----------	5,870 (101)	3,900	----------
691	167	H	.62	24	20	----------	6.9	2,360	3,760	5,040	----------	4,150 (82)	610	0
696	167	H	.62	24	20	35	6.6	3,080	4,570	5,510	----------	5,490 (100)	2,290	0
259	33	D	.59	24	20	35	5.4	3,340	4,780	5,900	6,230	1,590 (27)	0	0
368	85,94	D	.64	24	20	35	6.4	3,390	4,130	5,730	6,770	2,980 (52)	0	0
701	172	D	.62	24	20	35	6.1	4,040	5,600	6,170	----------	5,750 (93)	2,170	0
711	172	D	.62	24	20	----------	5.8	3,950	5,380	7,050	----------	4,980 (71)	2,070	----------
732	180	D	.62	24	20	----------	5.9	3,780	5,400	6,620	----------	4,750 (72)	0	0
737	180	D	.62	24	20	35	6.2	3,960	5,130	5,580	----------	4,760 (85)	1,100	0
752	185	D	.62	24	20	----------	5.8	4,390	5,290	6,090	----------	3,850 (63)	0	0
757	185	D	.62	24	20	35	5.7	4,080	5,530	6,160	----------	4,860 (79)	3,490	----------
763	196	BB	.62	24	20	35	5.9	4,030	5,060	6,360	----------	2,830 (44)	0	0
361	80	F	.62	24	20	35	6.3	2,870	4,320	6,350	5,730	0	0	0
769	201	X	.62	24	20	35	6.3	3,050	4,960	6,440	----------	4,440 (69)	0	0
576	133	AA	.62	24	20	35	6.0	3,460	4,820	5,850	6,520	3,440 (59)	0	0
765	197	AA	.60	24	20	35	5.8	3,750	5,430	4,820	----------	0	0	0
402	101	R	.62	24	20	35	6.3	3,680	4,940	6,290	5,900	2,440 (39)	0	0
415	107	V	.62	24	20	35	6.5	2,830	4,540	5,920	5,550	2,940 (50)	0	0
555	128	Y	.64	24	20	35	6.0	3,780	4,670	5,480	6,610	3,510 (64)	0	0
557	128	Y	.73	24	20	35	6.4	2,760	4,250	4,690	5,550	1,800 (38)	0	0
313	65	M	.60	24	20	35	5.9	3,150	3,950	6,050	5,680	2,250 (37)	0	0
366	77,96	G	.64	24	20	35	6.0	4,050	4,820	5,900	6,690	1,930 (33)	0	0
577	134	G	.62	24	20	35	6.3	3,910	5,610	6,730	7,320	6,140 (91)	3,340	1,300 (18)
702	173	G	.62	24	20	35	6.1	3,530	5,330	6,510	----------	5,290 (81)	3,270	----------
712	173	G	.62	24	20	----------	5.7	3,630	4,910	6,120	----------	5,880 (96)	5,660	----------
733	181	G	.62	24	20	----------	6.0	4,070	5,190	5,710	----------	6,040 (106)	4,150	----------
738	181	G	.62	24	20	35	5.9	3,810	5,080	6,290	----------	5,960 (95)	5,170	----------
753	186	G	.62	24	20	----------	5.9	3,750	5,420	6,290	----------	5,890 (94)	5,670	----------
758	186	G	.62	24	20	35	5.6	3,860	5,020	5,930	----------	5,800 (98)	7,290	----------
363	89	O1	.62	24	20	35	5.9	4,010	5,220	6,730	6,430	670 (10)	0	0
468	113	O2	.64	24	20	35	6.3	2,140	3,940	6,000	5,260	5,590 (93)	5,580	3,550 (67)
767	198	CC	.62	24	20	35	6.2	3,440	5,540	6,650	----------	5,330 (80)	2,390	----------
405	104	T	.62	24	20	35	6.4	2,940	4,380	5,530	5,860	280 (5)	0	0
416	108	W	.62	24	20	35	5.8	3,670	5,010	6,510	5,240	1,490 (23)	0	0
414	106	U	.62	24	20	35	6.1	3,030	4,410	6,430	5,900	2,490 (39)	0	0
362	79	N1	.62	24	20	35	6.1	3,220	4,600	6,970	6,550	4,000 (57)	950	0
403	102	N2	.62	24	20	35	5.9	3,860	5,640	6,630	5,720	4,410 (67)	1,860	0
575	132	Z	.62	24	20	35	6.0	4,760	5,160	6,490	6,510	4,970 (77)	2,210	0

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PORTLAND CEMENTS FROM DIFFERENT MILLS

RESISTANCE TO SULPHATE ACTION

Standard Portland cements from different manufacturing plants may differ greatly in sulphate resistance, as is well illustrated by the photographs of Plate 5 supported by the data given in Table 14. This fact was reported in 1926 (*34*) and subsequently (*36*, *38*). The reason for this is not clear. Behavior in sulphate waters of concrete and mortars made of Portland cements from 35 mills has been observed. Each of these cements was tested under four distinct exposure conditions as follows: (1) Half of one of the standard 7-day tensile strength briquets was stored in the laboratory in a 1 per cent solution of sodium sulphate, and its condition at six months was rated according to its appearance; (2) the companion half of the briquet

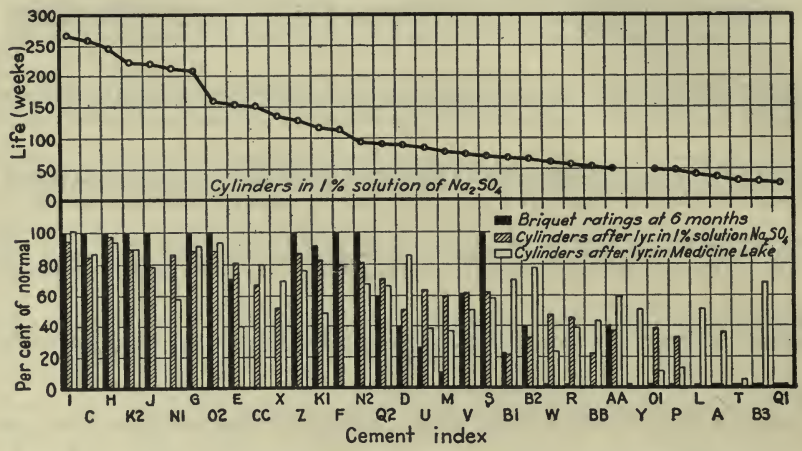

FIGURE 15.—Resistance to action of sulphate waters by cylinders and briquets made of standard Portland cements from 35 mills, as determined under different conditions of exposure (100 per cent normal represents: For cylinders, a strength ratio of 1.00; for briquets, a visual rating of 10). Note the general reliability of the briquet ratings by appearance after six months in 1 per cent solutions of Na_2SO_4 as compared with the change of volume and compression tests of the cylinders similarly exposed

exposed under the first condition was stored in the laboratory in a 1 per cent solution of magnesium sulphate and its condition at six months was rated according to its appearance; (3) cylinders that had not been air hardened were stored in the laboratory in 1 per cent solutions of sodium sulphate and their condition was rated by compression tests at one year and by length changes; (4) after five weeks of air hardening, cylinders were stored in Medicine Lake and their condition was rated by compression tests at one year.

The results of these tests are given in Table 15 and compared graphically in Figure 15. The values shown are average results where more than one lot of any cement was tested. Photographs of the briquets after six months in the sulphate solutions are reproduced in Plate 2. Study of Figure 15 shows that those cements that best resisted sulphate action under one condition of exposure ordinarily were resistant to action under the three other conditions.

Based on numerous repeat tests, the assumption that resistance of a cement is a characteristic fully as constant as any other property, seems justified.

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PHYSICAL AND CHEMICAL TESTS

Chemical analyses of one lot of each of 35 different brands of cement used in these experiments are given in Table 16. The average results of standard tests of these cements for time of setting, tensile strength, and fineness are shown graphically in Figure 16. Special determinations for fineness of 7 of the cements differing widely in resistance are recorded in Table 17.[6]

TABLE 15.—*Sulphate resistance of 35 standard Portland cements under different exposure conditions listed in order of resistance as indicated by life of cylinders*

[Excepting only E, F, M, and L, the same lots of cements were used for all tests]

Portland cement	Cylinders stored in 1 per cent Na_2SO_4		Medicine Lake, S. Dak., cylinders strength ratios at 1 year	Briquets rated visually at 6 months		Portland cement	Cylinders stored in 1 per cent Na_2SO_4		Medicine Lake, S. Dak., cylinders strength ratios at 1 year	Briquets rated visually at 6 months	
	Life [1]	Strength ratios at 1 year		Na_2SO_4 1 per cent	$MgSO_4$ 1 per cent		Life [1]	Strength ratios at 1 year		Na_2SO_4 1 per cent	$MgSO_4$ 1 per cent
	Weeks		*Per cent*				*Weeks*		*Per cent*		
I	266.0	94.7	101.6	10.0	10.0	M	77.6	60.0	37.0	1.0	8.0
C	257.0	85.0	87.0	10.0	10.0	V	75.0	61.0	50.0	6.1	7.0
H	246.0	97.0	94.0	10.0	10.0	S	72.3	62.0	58.0	10.0	10.0
K2	222.5	90.0	90.0	10.0	10.0	B1	70.0	21.3	69.8	2.2	4.9
J	220.0	79.0	----------	10.0	10.0	B2	65.9	32.5	77.0	4.0	7.0
N1	211.8	86.0	57.0	----------	----------	W	62.0	47.0	23.0	0	7.0
G	209.0	88.0	91.0	10.0	10.0	R	58.9	45.0	39.0	0	7.0
O2	159.7	87.0	93.0	10.0	10.0	BB	55.7	21.0	44.0	----------	----------
E	152.6	81.0	40.0	7.0	10.0	AA	51.3	37.0	59.0	4.0	10.0
CC	150.9	66.0	80.0	----------	----------	Y	----------	----------	51.0	0	4.0
X	137.1	52.0	69.0	----------	----------	O1	49.6	38.0	10.0	0	3.0
Z	127.9	87.0	77.0	10.0	10.0	P	48.7	33.0	12.0	0	3.0
K1	118.1	83.0	48.0	9.0	10.0	L	41.6	0	51.0	----------	----------
F	115.1	80.0	----------	10.0	10.0	A	36.9	0	35.7	0	3.5
N2	95.3	81.0	67.0	10.0	10.0	T	30.0	0	5.0	0	5.0
Q2	91.6	70.0	66.0	6.0	10.0	B3	29.2	0	68.0	0	4.0
D	91.6	50.0	86.0	4.0	8.7	Q1	27.0	0	0	0	3.0
U	86.1	64.0	39.0	2.6	6.0						

[1] Time required to increase 0.01 inch in length.

TABLE 16.—*Chemical analyses of Portland cements used*

[Chemical analyses by the Division of Tests, Bureau of Public Roads, U. S. Department of Agriculture, except for cements CC, X, and BB, which were analyzed by Bureau of Standards, U. S. Department of Commerce. Only one lot of each cement analyzed]

Portland cement	Silica (SiO_2)	Iron (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
I	21.71	3.39	6.53	62.50	1.59	1.77	1.84	99.33
C	22.43	3.20	5.03	62.54	3.75	1.91	1.20	100.06
H	21.13	2.73	8.89	62.40	.49	1.78	1.29	98.71
K2	21.45	2.65	6.45	62.50	2.97	1.82	1.95	99.79
J	20.47	3.58	6.24	61.82	3.94	1.85	1.95	99.85
N1	22.85	4.27	4.93	61.70	1.92	1.25	3.10	100.02
G	20.82	3.10	7.52	62.75	1.12	1.64	2.10	99.05
O2	24.87	2.39	4.57	61.30	1.26	1.58	3.60	99.57
E	21.93	3.42	6.31	62.29	3.44	1.33	1.22	99.94
CC	22.30	2.90	6.10	64.70	.70	1.70	1.10	99.50
X	22.00	2.70	5.50	61.90	4.60	1.80	1.00	99.50
Z	21.05	2.98	5.42	62.55	4.20	1.51	2.35	100.06
Average	21.92	3.11	6.12	62.41	2.50	1.66	1.89	99.62

[6] Throughout this discussion of cements from different mills, the arrangement of the material in all tables and figures is that of sulphate resistance as determined by the time required for 2 by 4 inch cylinders to increase in length 0.01 inch, recorded as the "life" in the second column of Table 15.

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TABLE 16.—*Chemical analyses of Portland cements used*—Continued

Portland cement	Silica (SiO_2)	Iron (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
K1	22.90	2.82	5.88	63.70	0.94	1.72	1.95	99.91
F	21.55	2.89	8.51	60.64	1.85	1.94	2.09	99.47
N2	21.74	3.10	6.38	63.06	1.99	1.76	1.47	99.50
Q2	22.45	2.33	5.92	62.70	1.79	1.87	2.70	99.76
D	21.12	2.48	6.82	61.24	5.24	2.01	1.90	100.81
U	22.40	3.22	6.83	62.65	1.34	1.22	2.15	99.81
M	21.80	2.57	7.69	62.05	2.46	2.16	1.18	99.91
V	21.50	2.80	6.30	62.08	1.21	1.80	3.70	99.39
S	21.52	3.30	5.63	61.40	5.00	1.34	1.53	99.72
B1	20.53	2.14	9.61	63.06	1.56	1.72	1.26	99.88
B2	22.40	2.42	6.48	63.05	1.76	1.49	2.20	99.80
W	21.15	2.70	7.40	63.35	1.77	1.37	2.25	99.99
Average	21.76	2.73	6.95	62.42	2.24	1.70	2.03	99.83
R	21.70	2.70	6.59	64.19	1.27	1.66	1.55	99.66
BB	21.30	2.70	7.20	64.80	.90	1.80	1.30	100.10
AA	20.65	3.64	8.86	62.51	1.75	1.49	1.04	99.94
Y	21.85	3.10	6.45	62.65	1.64	1.48	2.65	99.82
O1	21.60	3.46	5.04	62.75	2.68	1.68	2.75	99.96
P	22.50	3.06	6.39	62.95	1.30	1.56	2.25	100.01
L	22.22	3.20	8.06	62.60	.59	1.47	1.46	99.60
A	22.66	2.51	8.12	61.87	1.05	1.72	1.60	99.53
T	20.73	2.85	6.23	61.16	4.95	1.61	2.06	99.59
B3	20.97	4.19	6.71	63.43	1.45	1.65	1.54	99.94
Q1	21.28	3.14	7.72	61.33	2.65	1.53	1.90	99.55
Average	21.59	3.14	7.03	62.75	1.84	1.60	1.83	99.79
General average	21.76	2.99	6.69	62.52	2.20	1.66	1.92	99.74

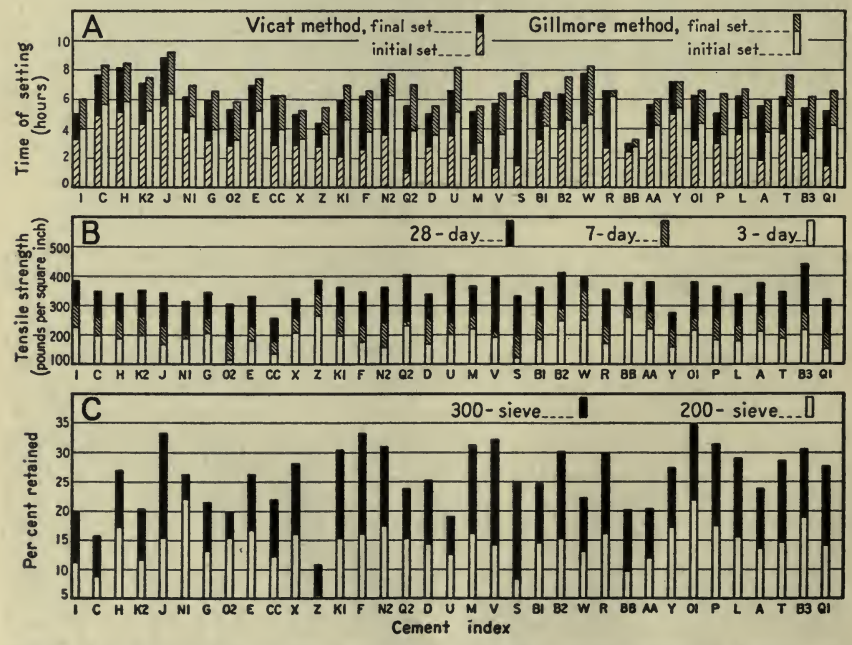

FIGURE 16.—Results of standard tests of 35 cements: A, Time of set; B, tensile strength; C, fineness. The order of the cements, from the left, is that of the life of cylinders in 1 per cent solutions of sodium sulphate. (Table 15)

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Examination of the data fails to disclose any trends that appear sufficiently significant to account for differences in resistance displayed by the cements. Perhaps the nearest approach to a trend is indicated by the chemical analyses in the quantities of alumina and iron considered together. Long ago Le Chatelier (*30*) advanced the theory that cements low in alumina and high in iron resist sea water best. Analyses in Table 16 support this conclusion when considered generally, but show many exceptions for individual cements.

COMPOUNDS IN THE CEMENTS

The actual composition of hydrated Portland cement is a subject outside the scope of this bulletin. It was deemed worth while, though, to calculate the compounds recorded in Table 18, after an adaptation by Bogue (*13*) of a method suggested by Colony (*1*), in order to bring out possible trends. The results are disappointing in that the table shows no decided trends, although wide differences in resistance are displayed by individual cements. Contrariwise, Thorvaldson (*49*), following a carefully conducted series of tests in which he used a few commercial cements and a number of specially prepared laboratory cements made of pure raw materials, stated among other conclusions that—

> The higher the lime content of the cement (i.e. the higher the percentage of tricalcium silicate), the aluminum remaining the same, the lower is the resistance to the action of the sulphates.

This did not consistently hold for the 35 commercial cements of Table 18.

TABLE 17.—*Fineness of seven Portland cements differing widely in resistance to sulphate waters*

[Analyses other than No. 200 sieve were made by Bureau of Standards, U. S. Department of Commerce]

Portland cement	Life in 1 per cent Na_2SO_4	Retained by No. 200 sieve	Retained by No. 325 sieve	Greater than 60 microns	Greater than 40 microns	Greater than 20 microns	Greater than 10 microns
	Weeks	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
I	266	15.3	25.3				83.5
C	257	9.1	17.2				81.8
H	246	15.9	25.4	33.8	47.9	66.0	84.1
K1	118	16.2	24.7	34.7	48.1	65.7	83.0
D	92	17.9	28.1				84.1
B1	70	17.0	17.4	32.3	46.9	63.4	80.8
A	37	18.2	29.7				83.8

RAW MATERIALS

Whether or not the degree of resistance of a commercial standard Portland cement is influenced by the constitution of the raw materials is difficult to determine, because many factors are involved in manufacturing the cements. However, there does appear to be a tendency for cements from adjacent plants, or from plants known to use similar raw materials, to behave alike in concrete exposed to sulphate action.

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TABLE 18.—*Calculated compounds (in per cent) of the Portland cements for which chemical analyses are shown in Table 16*

[For bases of these calculations refer to Paper No. 21 of the Portland Cement Association fellowship at the U. S. Bureau of Standards, Department of Commerce]

Group and Portland cement	Ignition loss	Free MgO	Free CaO	$CaSo_4$	$4CaOAl_2O_3Fe_2O_3$	$3CaOAl_2O_3$	$3CaOSiO_2$	$2CaOSiO_2$
Group 1:								
I	1.84	1.59	0.35	3.0	10.3	11.5	33.3	37.4
C	1.20	3.75	.14	3.2	9.7	7.9	39.6	34.5
H	1.29	.49	.35	3.2	8.3	18.9	22.5	43.6
K2	1.95	2.97	.46	3.1	8.1	12.6	37.1	33.6
J	1.95	3.94	(1)	3.1	10.9	10.4	43.6	25.8
N1	3.10	1.92	(1)	2.1	13.0	5.6	35.2	38.0
G	2.10	1.12	.92	2.8	9.4	14.7	33.7	34.4
O2	3.60	1.26	.52	2.7	7.3	8.1	19.5	56.7
E	1.22	3.44	(1)	2.3	10.4	10.9	35.6	36.0
CC	1.10	.70	(1)	2.9	8.8	11.2	43.8	31.0
X	1.00	4.60	(1)	3.1	8.2	10.0	38.7	34.0
Z	2.35	4.20	(1)	2.6	9.1	9.3	49.5	23.0
Average	1.89	2.50	.46	2.8	9.5	10.9	36.0	35.7
Group 2:								
K1	1.95	.94	(1)	2.9	8.6	11.8	36.6	38.1
F	2.09	1.85	.64	3.3	8.8	17.6	13.4	51.7
N2	1.47	1.99	.29	3.0	9.4	11.7	37.8	33.9
Q2	2.70	1.79	1.12	3.2	7.1	11.7	31.4	40.1
D	1.90	5.24	.88	3.4	7.5	13.9	30.0	38.0
U	2.15	1.34	(1)	2.1	9.8	12.6	30.6	41.2
M	1.18	2.46	Trace.	3.7	7.8	16.0	25.2	43.6
V	3.70	1.21	(1)	3.1	8.5	11.9	37.8	33.2
S	1.53	5.00	(1)	2.3	10.0	9.3	39.8	21.9
B1	1.26	1.56	.38	2.9	6.3	22.0	26.6	38.9
B2	2.20	1.76	(1)	2.5	7.4	13.1	35.0	37.9
W	2.25	1.77	(1)	2.3	8.2	15.0	39.5	30.9
Average	2.03	2.24	.55	2.9	8.3	13.9	32.0	37.5
Group 3:								
R	1.55	1.27	(1)	2.8	8.2	12.9	43.3	29.6
BB	1.30	.90	(1)	3.1	8.2	14.5	44.4	27.7
AA	1.04	1.75	(1)	2.5	11.1	17.3	28.4	37.8
Y	2.65	1.64	(1)	2.5	9.4	11.8	36.7	35.0
O1	2.75	2.68	.52	2.9	10.5	7.5	45.4	27.8
P	2.25	1.30	(1)	2.6	9.3	11.7	33.4	39.4
L	1.46	.59	(1)	2.5	9.7	15.9	22.9	46.5
A	1.60	1.05	.52	2.9	7.6	17.2	14.4	54.2
T	2.06	4.95	1.60	2.7	8.7	11.7	34.2	33.7
B3	1.54	1.45	(1)	2.8	12.7	10.7	42.9	27.8
Q1	1.90	2.65	(1)	2.6	9.5	15.1	27.1	40.6
Average	1.83	1.84	.88	2.7	9.5	13.3	33.9	36.4
General average	1.92	2.20	.58	2.8	9.1	12.7	34.0	36.5

[1] No data.

The 35 cements of Table 15 came from plants located in 15 States of the United States, mostly in the upper Mississippi River basin and the far West, and from two Canadian Provinces. Nearly all the highly resistant cements came from the relatively small area in Illinois, Iowa, Kansas, and Missouri indicated by cross-hatching in Figure 17, whereas none of the low-resistance cements came from this area. Of the 10 cements tested from plants within this area, 6 were among the 7 most resistant of the 35, and all 10 were among the 14 most resistant. It may be significant or merely coincidental that 9 of these 10 cements came from plants using raw materials from the Carboniferous geological system. It has not been possible to obtain complete information on the geological origin of all raw materials used at each plant, but apparently limestone from the Carboniferous system was used at not more than 13 of the 35 plants and shale from the same system at possibly 10 plants.

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With so high a proportion of the resistant cements coming from plants using raw materials of the same geological age taken from a restricted area, and considering the other data, it seems logical to conclude that the raw materials used in the manufacture of a standard Portland cement are a factor in its resistance to sulphate action.

SUGGESTED TEST FOR SULPHATE RESISTANCE

To eliminate cements very low in resistance from consideration for concrete that is to be exposed to the action of sodium sulphate or magnesium sulphate, the following test routine in suggested:

One-half of each of the three briquets used in the standard 7-day tensile test should be stored in a 5 per cent solution of sodium sulphate and the companion half in a 5 per cent solution of magnesium sulphate. To make these 5 per cent solutions, on the basis of anhydrous salts, requires 3 ounces of room-dry salt per gallon of water. Not more than 15 briquet halves should be stored in each gallon of solution, which should be renewed completely every 4 weeks. It is desirable that the temperature of the solutions be maintained as near 70° F. as practicable. Earthenware jars, covered to reduce evaporation, are satisfactory and convenient containers.

FIGURE 17.—Portland cements from 10 mills in the cross-hatched area were among the 14 most resistant to sulphate attack of 35 cements used in the tests

Briquets made of highly resistant cements and stored under the conditions prescribed will show little or no visible action in either solution in less than 16 weeks excepting, perhaps, a slight rounding of the edges. Briquets made of cements very low in resistance, when subjected to this test, will have almost completely disintegrated in 16 weeks. The value of the test as outlined will be greatly increased if briquets made of cements from several mills are included in order to give a basis for directly comparing behavior. If this is done, the failure of any cement falling well below average will be more convincing.

The feasibility of speeding up this 16-week test by increasing the strength of the solution, by keeping the solution at higher temperatures, by using leaner mixes, and in numerous other ways, has been tried without satisfactorily consistent results. A more accelerated test of equal reliability is greatly to be desired, but can not yet be offered.

SUMMARY OF RESULTS WITH DIFFERENT PORTLAND CEMENTS

Standard Portland cements from different mills may differ greatly in resistance to the action of sulphate waters. Under identical exposure conditions, concrete and mortar made of resistant cements may

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last 10 times as long as that made of cements of low resistance. The reason for this is not known.

Results of standard physical tests give no indication of the resistance of a cement to sulphates, nor do ordinary chemical analyses. Differences in the raw materials associated with the geological formations from which they come may be factors.

With Portland cements differing so greatly in resistance to sulphate action, certainly the first consideration for all concrete that is to be so subjected should be the cement itself, and, regardless of all other precautions, the use of any cement of low resistance should be avoided. Until a more accelerated test of equal reliability is developed, the 16-week test outlined on page 43 herein is recommended.

SPECIAL CEMENTS OTHER THAN ALUMINA CEMENTS

The alkali resistance of 14 special cements was investigated. Cylinders of 10 of these cements were stored both in laboratory solutions and in Medicine Lake, while cylinders of the other 4 were tested under either one or the other of these conditions. For comparison, cylinders made of 7 Portland cements were tested with this group. Standard physical tests of the special cements are recorded in Table 19, and chemical analyses of seven of them in Table 20. Table 21 shows the resistance of these special cements and of some companion Portland cements under three exposure conditions. There follows a general description of essential characteristics of these special cements together with a summarized account of behavior, based on the data in Table 21 and in Table 22. Plate 6 shows photographs of several of the Medicine Lake series.

TABLE 19.—*Standard physical tests of 14 special cements*

Special cements	Time of set								Soundness	Fineness		Normal consistency	Specific gravity	Tensile strength of briquets		
	Vicat				Gillmore											
	Initial		Final		Initial		Final			Retained by No. 200 sieve	Retained by No. 300 sieve			3 days	7 days	28 days
	H.	*M.*	*H.*	*M.*	*H.*	*M.*	*H.*	*M.*		*Per cent*	*Per cent*			*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
X	4	0	9	45	5	45	10	30	O.K.	4.0	19.5	38.75	2.81	290	384	577
B	3	0	5	50	3	40	6	15	do	5.5	14.5	24.75	3.13	225	250	381
H	3	20	4	40	3	10	4	45	do	3.2	37.4	28.00		281	423	466
I	1	40	3	40	2	35	3	50	do	.4	1.1	33.00		325	362	371
A2	4	40	18	30	5	30			do	7.7	29.1	24.25	3.14	122	184	324
A3	5	20	8	35	5	35	9	5	do	8.0	15.5	23.25	3.18	127	208	330
A1	5	10	6	40	5	50	7	5	do	12.0	17.9	24.25	3.12	145	206	319
C	3	15	5	45	3	55	6	10	do	10.2	19.3	24.50	3.16	210	276	388
G	3	40	6	15	4	45	6	30	do	6.4	14.5	33.00		167	213	305
D	1	0	3	5	1	40	3	35	do	1.9	28.1	28.25		372	430	465
E	3	10	4	40	3	0	4	30	do	6.4	51.1	26.00		293	325	366
F	1	25	3	30	2	35	5	10	do	4.5	39.3	28.75		365	403	446
L		9		17		20		36	do	11.4	20.2	33.50		99	109	136
K	4	5	7	45	4	15	7	5	do	7.4	18.8	27.00	3.13	201	263	

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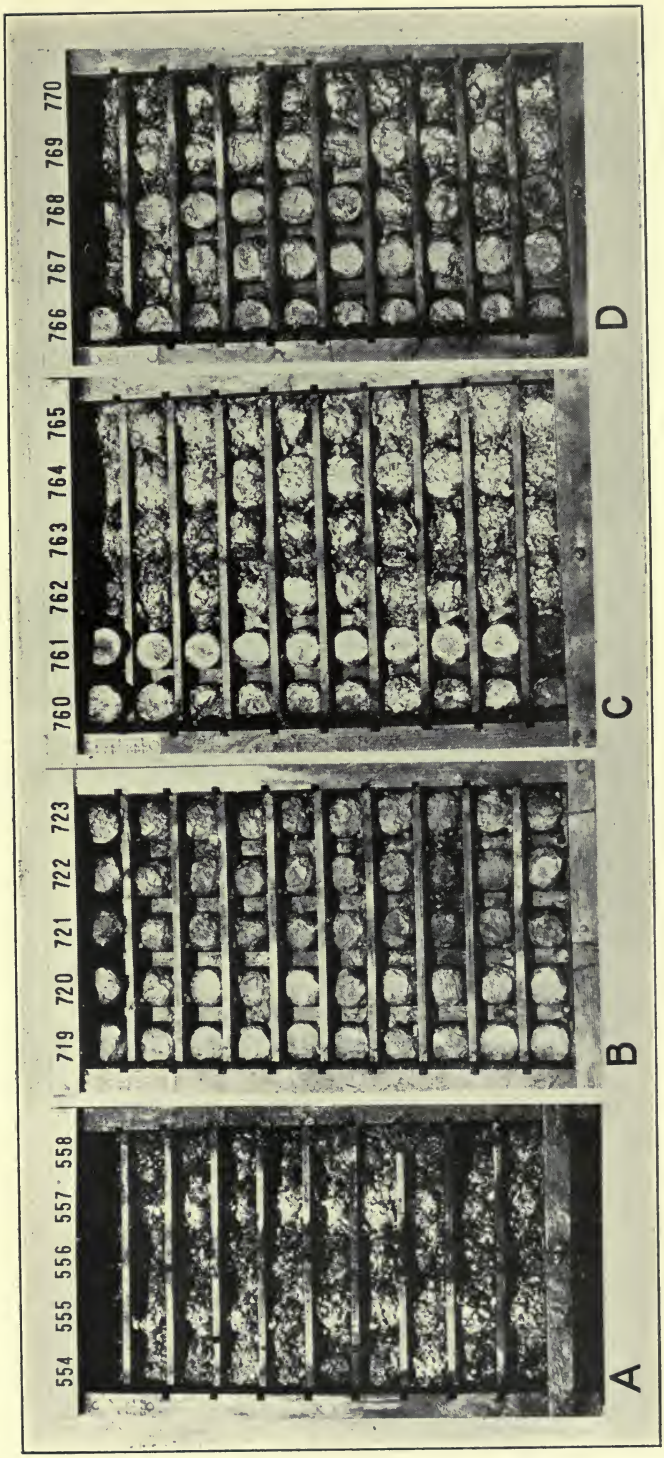

CYLINDERS MADE OF SPECIAL CEMENTS OTHER THAN HIGH ALUMINA, AFTER STORAGE IN MEDICINE LAKE

A, After five years. Series 554—one-half Portland A, one-half Portland B1; Series 555 and 557—Portland Y; series 556 and 558—special A2. B, After four years special cement X. Series 719, mix 1: 0.94; series 720 and 721, mix 1: 1.88; series 722, mix 1: 2.82; series 723 mix 1: 4.70. C, After two and one-half years. Series 761, 763 and 765, standard Portland cements from different mills; series 760, 762 and 764 special cements from the same mills, respectively. D, After two and one-half years. Series 767 and 769, standard Portland cements from different mills; series 766 and 768, special cements from the same mills, respectively

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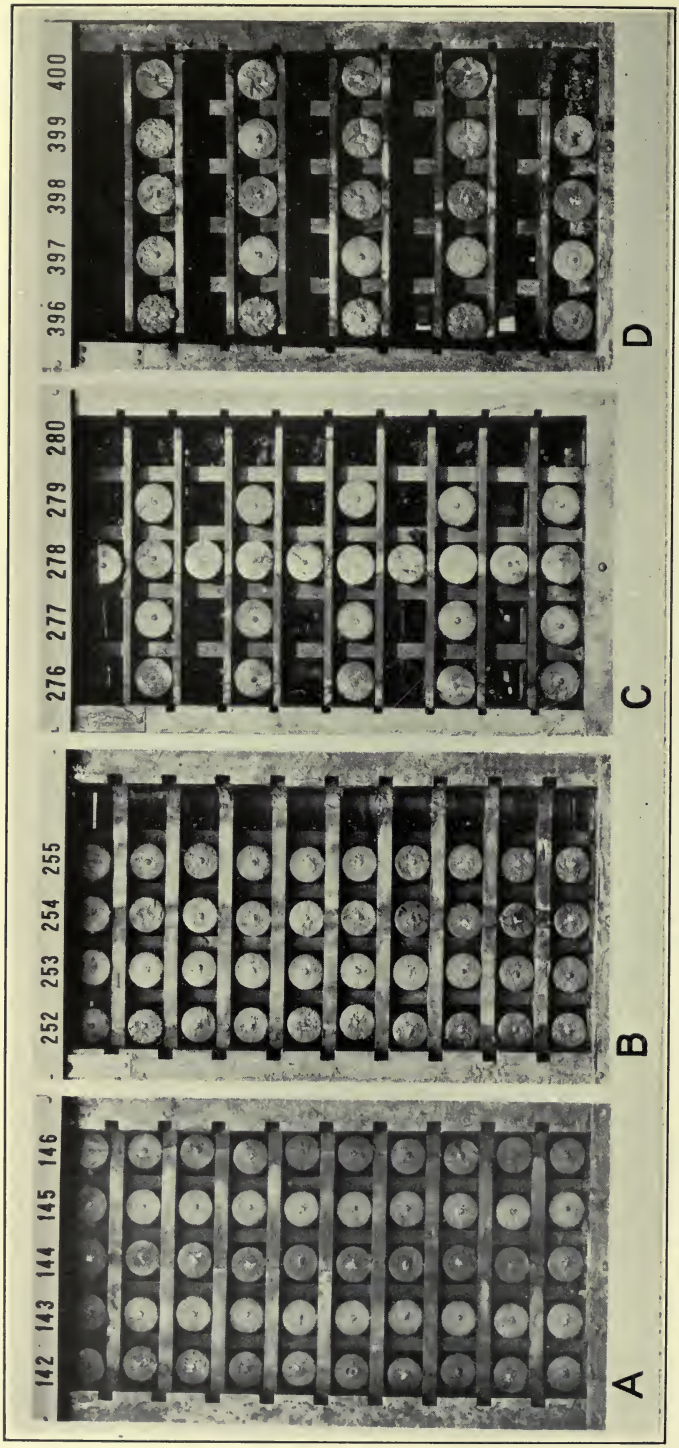

CYLINDERS MADE OF HIGH ALUMINA CEMENTS AFTER STORAGE IN MEDICINE LAKE

A, Ottawa sand mortar cylinders made of alumina cement Ac1 after seven years in the lake. Series 142 to 146, respectively, stored in distilled water 27 days, in moist air 72 hours, in water vapor at 100° F. for 48 hours, in water vapor at 155° F. for 48 hours, and in steam at 212° for 48 hours. B, Made of alumina cement Ac2 after six and a half years in the lake. C, Ottawa sand mortar cylinders made of alumina cement Ac3 after six years in the lake. Mixes for series 276 to 280, respectively, were 1:2, 1:3, 1:3, 1:4, and 1:5. D, Made of alumina cement Ac3 after six years in the lake. Water ratios for series 396 to 400, respectively, were 0.44, 0.53, 0.59, 0.73, and 0.88

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TABLE 20.—*Chemical analyses* [1] *of 7 special cements*

Special cement	Silica (SiO_2)	Iron (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
X	35.85	3.66	6.14	48.60	1.01	1.53	3.20	99.99
B	21.40	3.93	5.82	62.29	1.86	1.98	2.58	99.86
A2	22.37	3.43	5.95	62.51	2.57	1.73	1.36	99.92
C	21.16	3.26	11.01	58.45	1.77	1.87	2.47	99.99
D	20.50	2.54	5.86	64.35	1.01	2.37	3.40	100.03
L	21.60	3.95	11.45	51.20	.53	4.12	6.85	99.70
K	21.70	.61	7.01	60.00	6.67	1.46	2.14	99.59

[1] Analyses by the Division of Tests, Bureau of Public Roads, U. S. Department of Agriculture.

TABLE 21.—*Resistance to the action of sulphate waters of 14 special cements under different conditions of exposure and of some companion Portland cements*

Cement	Stored in 1 per cent solution of Na_2SO_4		Strength ratio at 1 year in Medicine Lake	Stored in tap water	
	Life	Strength ratio at 1 year		Age	Length increase
	Weeks	*Per cent*	*Per cent*	*Weeks*	*Inch*
Special X	(1)	106	100	260	0.0016
Special B	235.0	95	105	235	.0015
Portland F [2]	115.1	80	----------	115	.0007
Special H	208.0	84	86	208	.0011
Portland CC	150.9	66	80	151	.0006
Special I	198.0	99	83	198	.0029
Portland I	(3)	93	91	----------	----------
Special A2	----------	----------	90	----------	----------
Special A3	197.5	81	87	198	−.0007
Special A1	----------	----------	75	----------	----------
Portland Y	----------	----------	51	----------	----------
Special C	163.5	85	93	164	.0001
Portland F [2]	115.1	80	----------	115	.0007
Special G	156.0	66	74	156	.0012
Portland X	137.1	52	69	137	.0010
Special D	125.9	97	90	126	.0006
Special E	121.6	72	60	122	.0021
Portland AA	33.4	0	0	33	.0003
Special F	110.3	60	58	110	.0009
Portland BB	55.7	21	44	56	−.0003
½ special L, ¼ Portland A, and ¼ Portland B1	80.3	53	----------	80	−.0026
Special K	25.0	0	----------	----------	----------

[1] Life not yet determined. Strength ratio at 5 years, 94 per cent.
[2] Cylinders with Portland cement F were made 25 months before the cylinders with special cements B and C, and direct comparisions of resistance are therefore not satisfactory.
[3] Not yet determined.

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TABLE 22.—*Tests of 2 by 4 inch cylinders made of special cements other than high alumina and exposed to the action of sulphate water in Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions, is an average of 5 cylinders made on different days. Figures in parentheses indicate per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water]

Series	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hrs.	*Days*	*Days*	*Per cent*							
573	130	Special B	0.62	24	20	35	6.3	4,140	4,800	5,610	8,270	5,880 (105)	3,710	610 (7)
714	175	Special D	.64	24	20	35	5.6	5,080	6,040	6,250	-----	5,620 (90)	0	0
574	131	Special C	.62	24	20	35	6.6	3,490	4,580	6,100	7,220	5,680 (93)	3,360	1,130 (16)
764	191	Special E	.62	24	20	35	3.8	4,480	5,280	5,990	-----	3,570 (60)	0	0
765	197	Portland AA	.60	24	20	35	5.8	3,750	5,430	4,820	-----	0	0	0
762	200	Special F	.62	24	20	35	5.6	5,390	6,610	6,660	-----	3,830 (58)	0	0
763	196	Portland BB	.62	24	20	35	5.9	4,030	5,660	6,360	-----	2,830 (44)	0	0
768	193	Special G	.62	24	20	35	5.9	2,910	4,410	5,930	-----	4,410 (74)	810	0
769	201	Portland X	.62	24	20	35	6.3	3,050	4,960	6,440	-----	4,440 (69)	0	0
[1] 467	112	Special X	.54	24	20	35	----	2,830	4,390	4,820	4,350	4,830 (100)	3,570	2,640 (61)
[2] 719	177	do	.44	24	20	35	10.7	3,940	5,200	5,660	-----	4,940 (87)	4,520	----------
[1] 720–721	177	do	.54	24	20	35	8.0	3,000	4,400	5,100	-----	4,340 (85)	3,730	----------
[3] 722	177	do	.61	24	20	35	6.6	2,690	4,020	4,220	-----	3,710 (88)	3,500	----------
[4] 723	177	do	.90	24	20	35	8.2	860	1,530	2,230	-----	1,700 (76)	210	0
[2] [5] 724	177	do	.42	24	20	35	9.5	4,280	5,900	6,680	-----	6,070 (91)	6,220	----------
[16] 725–726	177	do	.51	24	20	35	9.4	2,450	4,080	4,240	-----	3,960 (93)	3,760	----------
[3] [5] 727	177	do	.70	24	20	35	13.3	1,200	2,370	3,050	-----	2,150 (70)	1,400	----------
[4] [5] 728	177	do	1.08	24	20	35	15.8	320	780	990	-----	0	0	0
766	192	Special H	.62	24	20	35	6.0	6,360	6,480	7,570	-----	6,520 (86)	5,160	----------
767	198	Portland CC	.62	24	20	35	6.2	3,440	5,540	6,650	-----	5,330 (80)	2,390	----------
760	190	Special I	.64	24	20	35	4.7	4,920	5,570	5,780	-----	4,810 (83)	2,590	----------
761	199	Portland I	.62	24	20	35	6.0	4,160	4,830	7,560	-----	6,900 (91)	5,370	----------
243–247	28	Special A1	.62	24	20	35	6.2	2,910	3,770	5,370	5,960	4,030 (75)	0	0
[5] 248–250	10	Special A3	.63	24	20	35	9.5	1,430	2,730	3,750	3,620	3,280 (87)	800	0
556	127	Special A2	.64	24	20	35	6.0	3,200	4,720	5,950	7,080	5,330 (90)	0	0
555	128	Portland Y	.64	24	20	35	6.0	3,780	4,670	5,480	6,610	3,510 (64)	0	0
558	127	Special A2	.73	24	20	35	6.6	2,280	4,480	5,290	6,070	3,080 (58)	0	0
557	128	Portland Y	.73	24	20	35	6.4	2,760	4,250	4,690	5,550	1,800 (38)	0	0
[6] 561	127	Special A2	.62	24	[7] 20	35	7.9	3,260	4,720	5,860	5,770	6,090 (104)	4,120	0
[6] 560	128	Portland Y	.62	24	[7] 20	35	8.2	3,550	5,160	6,120	6,140	5,270 (86)	4,040	0
[6] 563	127	Special A2	.71	24	[7] 20	35	9.1	2,290	4,520	4,960	6,100	3,960 (80)	1,140	0
[6] 562	128	Portland Y	.71	24	[7] 20	35	9.2	2,720	4,290	5,450	5,810	3,920 (72)	900	0

[1] Mix 1 : 1.88.
[2] Mix 1 : 0.94.
[3] Mix 1 : 2.82.
[4] Mix 1 : 4.70.
[5] Standard Ottawa sand cylinders.
[6] Mix 1 : 2.25 (fineness modulus=3.10).
[7] Time in damp sand.

Special cement X is an imported mason's cement containing about 33⅓ per cent diatomaceous silica mixed with the cement clinker before grinding. Tests with this cement are of unusual interest both because of the siliceous nature of the admixture and because of the method of adding. Therefore the cement was differently proportioned in a number of mixes. The results of the tests are interpreted to indicate that, weight for weight, resistance of this special cement is about equal to that of the more resistant Portland cements although, since one-third of the material added is without cementaceous properties by itself, the concrete under all conditions is somewhat lower in unit strength. No check tests of this cement without the admixture are available and therefore conclusions on the exact effect of the admixture on resistance are impossible. However considered, special cement X made an excellent showing in 1 per cent solutions of sodium sulphate and did reasonably well in Medicine Lake.

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Special cement B is reground Portland cement F, and special cement C is the same as B with a carborundum preparation added during regrinding. No test exactly parallel to that made on special cement B was made on Portland cement F, and therefore the specific effect of regrinding is not known. The resistance of special cement B was somewhat greater than that of special cement C, although neither displayed greater resistance than that of the more resistant Portlands.

The five special cements, D, E, F, H, and I have been developed in recent years to meet demands for high-early-strength concrete. The last four of these have been tested parallel with companion Portland cements AA, BB, CC, and I, respectively. No companion Portland cement was available for testing with special cement D, but the resistance displayed by this cement has been, at best, no greater than that of an average Portland cement. As evidenced by the tests, special cements E, F, and H did not display outstanding resistance, although they were somewhat more resistant than their companion Portland cements. Special cement I was slightly less resistant than its highly resistant companion Portland cement I.

Special cements A1, A2, and A3 are standard Portland cements, from different mills, to which tannic acid treated with gypsum was added during grinding. Portland cement Y is the same cement as special cement A2 without the gypsum. Results of tests at one year are slightly more favorable for the treated cement, but after three years no difference between the treated and untreated cement was apparent.

Special cement G is a soap-treated water-repellent product, otherwise the same as Portland cement X with which parallel tests were made. The treated cement displayed resistance differing very little from that of the untreated.

Special cement L is a natural cement somewhat higher in alumina and SO_3 and lower in lime than normal Portland cement. Its use with 50 per cent Portland cement is recommended. Used in this manner, it produced a concrete of slightly greater resistance than that of concrete made with only Portland cement from the same lot.

Special cement K is a white cement very low in iron and high in magnesia, with other constituents about the same as those of normal Portland cement. This product made a very poor showing in alkali resistance.

With the possible exception of cement X, none of the special cements tested showed increased resistance to sulphate action in a degree warranting preference over the more resistant of the Portland cements.

ALUMINA CEMENTS

Alumina cements, according to Bied (*11*) were discovered by him in 1908 "in seeking a binder which would not be attacked either by sea water or by sulphated waters". In the United States, Spackman (*45*) in 1910 reported upon the aluminates, their properties and possibilities in cement manufacture, basing his report on experiments begun in 1902 and resulting, in November, 1908, in the making of 1,000 pounds of calcium aluminate which was used experimentally for many purposes for which Portland cement is used (*17*). Therefore there is some question as to who should have the credit for discovering alumina cements, although there is no question that they

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were first manufactured and utilized commercially by the French. Because they possessed the property of early hardening, although setting no more quickly than standard Portland cement, the French Army used alumina cements in foundations for gun platforms and in other emergency construction during the World War. Thereafter the use of these cements extended rapidly to many other types of engineering structures.

Manufacture of alumina cement was begun in the United States early in 1924, and in June of the same year cylinders were made in the draintile laboratory at University Farm. These cylinders were exposed when 8 weeks old to the sulphate water of Medicine Lake, in which cylinders of one of the French alumina cements were already exposed.

CHEMICAL COMPOSITION

The raw materials of which alumina cements are made are bauxite and limestone, or bauxite and lime, and these cements are essentially calcium aluminates very low in silica (*7*, *20*, *45*), whereas standard Portland cements are essentially calcium silicates low in alumina. The chemical composition of the three alumina cements used in these experiments is shown in Table 23, in which is also shown the average of the chemical analyses of the 35 standard Portland cements of Table 16. It will be noted in Table 23 that the oxides of calcium, silicum, aluminum, and iron average approximately 63, 22, 7, and 3 per cent in the Portland cements as compared with 38, 8, 42, and 11 per cent in the high-alumina cements. As evidenced by these analyses, the three alumina cements are strikingly similar in composition and have consistently behaved similarly in the various tests to which subjected.

TABLE 23.—*Chemical analyses of 3 brands of alumina cements compared with average for 35 Portland cements*

Radical	Portland cements (average)	Alumina cements			
		Ac1	Ac2	Ac3	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)	21.76	9.42	8.91	4.71	7.68
Iron (Fe_2O_3)	2.99	14.02	8.44	10.96	11.14
Alumina (Al_2O_3)	6.69	40.60	41.59	42.72	41.64
Lime (CaO)	62.52	35.23	40.92	39.06	38.40
Magnesia (MgO)	2.20	.50	.35	.66	.50
Sulphuric anhydride (SO_3)	1.66	Trace.	----------	.35	.12
Loss on ignition	1.92	.15	.08	1.84	.69
Total	99.74	99.92	100.29	100.30	100.17

EXPOSURE CONDITIONS FOR ALUMINA CEMENTS

Each of the three alumina cements tested was used in cylinders exposed in Medicine Lake, while the behavior of two of them was also observed in cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate. Supplementing the experiments with cylinders, draintile of alumina cement Ac3 were manufactured at two commercial tile plants. Some of the tile were placed in Medicine Lake and others were buried in alkali soils in southwestern Minnesota and southeastern North Dakota. In addition to check cylinders stored in tap water in the laboratory according to the regular practice check cylinders

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of the two alumina cements Ac1 and Ac3 were buried below frost in two soils free of acids and alkalies, as were the check draintile of Ac3 cement. Curing temperatures to which the alumina specimens were subjected were normal except that cylinders of the cement Ac1 were cured also in water vapor at 100°, 155°, and 212° F.

UNUSUAL PROPERTIES REVEALED BY LONG-TIME TESTS

It became evident during the work with alumina cements, that these cements had other properties besides early hardening that were not common to standard Portland cements. For instance, check cylinders stored in tap water frequently expanded nearly as much as cylinders in sulphate solutions in the same room, thereby largely nullifying the value of such tests as an index of sulphate action on alumina cements. In Figures 18 and 19 the length increases of alumina concrete and mortar cylinders stored in tap water are shown in comparison with those of standard Portland cement cylinders stored in the same tank. The compression tests of these alumina-cement cylinders, shown in the same figures, revealed that all these alumina cements lost strength with age as they increased in volume but, contrary to what would be expected, while alumina cement Ac3 increased most in volume it showed the least loss of strength.

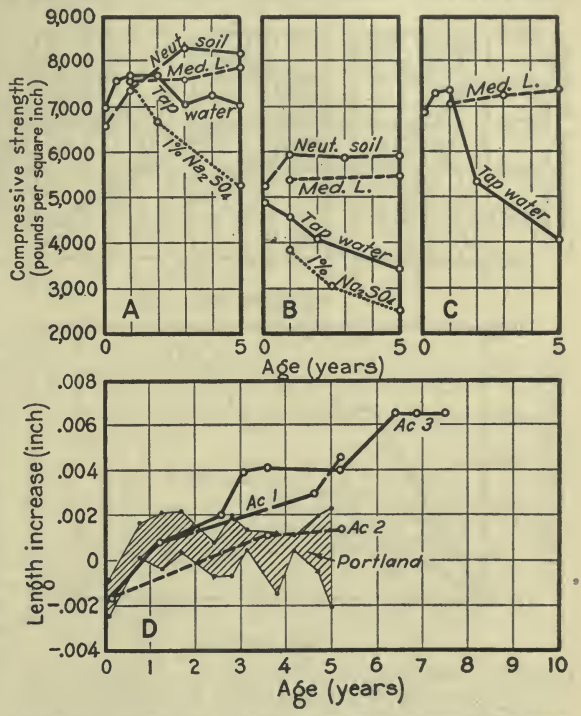

FIGURE 18.—Strength and length changes of standard laboratory cylinders made of alumina cements: A, Cylinders of alumina cement Ac3 stored in neutral soil, in Medicine Lake, in tap water, and in sodium sulphate solution; B, cylinders of alumina cement Ac1 stored in neutral soil, in Medicine Lake, in tap water, and in sodium sulphate solution; C, cylinders of alumina cement Ac2 stored in Medicine Lake and in tap water; D, length changes in cylinders of alumina cements stored in tap water compared with range of length changes of Portland cement cylinders made in 98 series from 35 brands. Each point for the alumina cements is the average for 5 to 35 cylinders

Other graphs of Figures 18 and 19 show compression tests of cylinders made with two of the alumina cements buried below frost in two soils with neutral reactions for periods up to five years. None of these cylinders lost strength with age; there was instead a very definite tendency toward increase in strength. Difference in behavior of the laboratory cylinders stored in tap water and of the cylinders buried in damp soils out-of-doors could be attributed either to dissimilar tem-

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peratures or to the only obvious alternative, some deleterious effects produced by water curing but not by moist soil. The latter hypothesis, however, is scarcely tenable because, as shown in Figures 18 and 19, the alumina-cement cylinders in the highly mineralized but relatively cool water of Medicine Lake invariably had 5-year strengths exceeding those of the cylinders in the comparatively warm laboratory solutions in which the salt content was much lower.

Cylinders of alumina cement Ac1 were subjected to air hardening in the laboratory for periods of 0, 2, 4, 8, and 49 weeks without appreciably different effects on compressive strength at any period up to five years, as shown in Figure 20. The effect of air hardening on volume change was likewise inappreciable, except for the 49-week period which markedly reduced expansion.

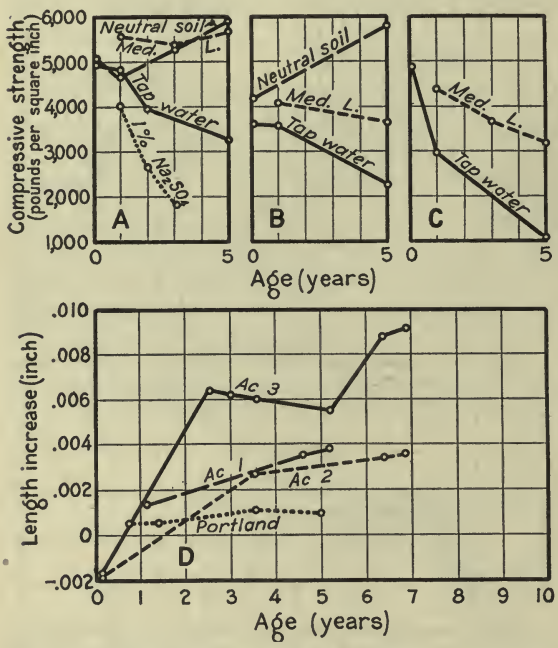

FIGURE 19.—Strength and length changes of mortar cylinders made of alumina cements and standard Ottawa sand: A, Cylinders of alumina cement Ac3 stored in neutral soil, in Medicine Lake, in tap water, and in sodium sulphate solution; B, cylinders of alumina cement Ac1 stored in neutral soil, in Medicine Lake, and in tap water; C, cylinders of alumina cement Ac2 stored in Medicine Lake and in tap water; D, cylinders of alumina cements compared with those of a brand of standard Portland cement. Each point is the average for 5 to 10 cylinders made on 5 different days

With very evidently negative reactions to mildly high room temperatures for three alumina cements, it is interesting to note the effect produced by curing cylinders of cement Ac1 in water vapor at temperatures of 100°, 155°, and 212° F., as shown by Figure 20. These data reveal that in the cylinders stored in tap water the greatest increases of volume followed curing at 100° and very slight to negative increases followed curing at 155° and 212°. The cylinders cured at 155° behaved essentially the same as those of many Portland cements cured at ordinary room temperatures. High-temperature curing reduced compressive strengths at all periods tested up to 5 years, excepting only 100° curing at 1 year and less, although the cylinders cured at 155° and 212° most nearly maintained their 28-day strengths for 5 years.

With cylinders of the alumina cement Ac3, varying the water-cement ratio and the quantity of cement in the mix gave entirely consistent results as illustrated in Figure 21.

SULPHATE RESISTANCE OF ALUMINA CEMENTS

Under the conditions imposed by the field tests, the degree of resistance displayed by the three alumina cements approached the ideal, whereas the results obtained in the laboratory were considerably less satisfactory. Conclusions as summarized are:

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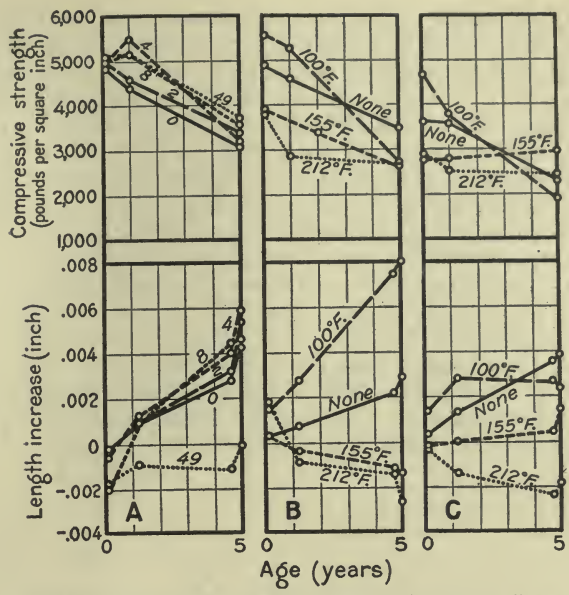

FIGURE 20.—Compressive strengths and length changes of cylinders of alumina cement Ac1 stored in tap water, as influenced by varying the curing conditions: A, Concrete cylinders hardened in air for the number of weeks indicated, after 20 days curing in water; B, concrete cylinders cured 48 hours in water vapor at temperatures indicated; C, mortar cylinders cured 48 hours in water vapor at temperatures indicated. Each point is the average for five cylinders made on different days

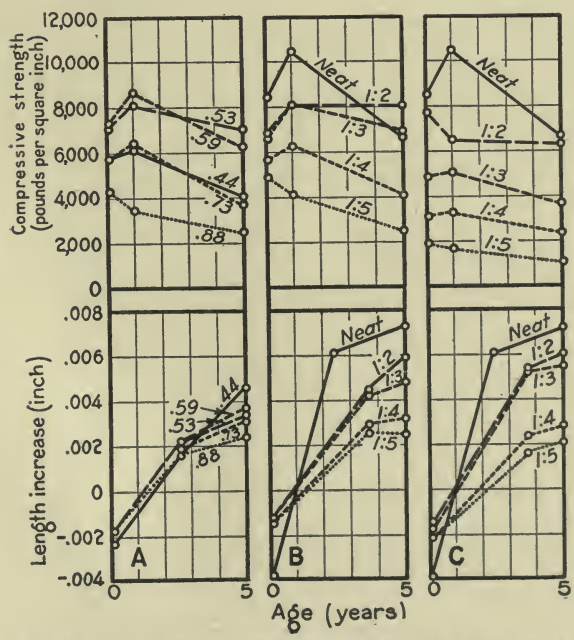

FIGURE 21.—Compressive strengths and length changes of cylinders of alumina cement Ac3 stored in tap water: A, Concrete cylinders with water-cement ratios as shown; B, neat cement cylinders and concrete cylinders of mixes as shown; C, neat cement cylinders and mortar cylinders of mixes as shown. Each point is the average for five cylinders made on different days

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Medicine Lake water was resisted remarkably well by the three alumina cements. This is clearly shown by the compression tests up to five years and by appearances up to seven and one-half years. (Table 24 and pl. 7.) Resistance was so pronounced that for 34 of the 53 series of alumina cement cylinders crushing strengths were higher after 5 years in the lake than they were at 1 year, while the loss of strength was less than 9 per cent in 10 of the remaining 19 series. Of the other 9, the cylinders of series 142, 147, and 156, without air hardening previous to exposure, showed strength losses of 10, 15, and 12 per cent, respectively, during the 4 years; those of 1:5 concrete of series 291 had lost 22 per cent; and those of series 254–255, of standard Ottawa sand in 1:3 mortar, had lost 27 per cent of their strength. Cylinders of series 280 and 292, of standard Ottawa sand in 1:5 mix, with high water-cement ratios, failed the first year. The wet-mixed 1:3 concrete cylinders of series 400 were weaker at 3 and 5 years than at 1 year and were showing evidence of considerable deterioration, but tested only 16 per cent weaker at 5 years than at 1 year.

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TABLE 24.—*Tests of 2 by 4 inch cylinders made of high alumina cements cured in water and water vapor and exposed to the action of sulphate waters of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions, is an average of 5 cylinders made on different days. Figures in parentheses, in compression-test columns, indicate per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water in the laboratory]

Series	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*							
137	14	Alumina Acl	0.64	24	--------	48	155	25	6.2	3,250	3,550	2,830	2,850	3,400 (120)	4,510	4,290 (151)
138	14	do	.64	24	--------	24 24	155 212	25	6.2	3,150	3,670	2,860	2,510	3,320 (116)	--------	4,960 (198)
139	14	do	.64	24	--------	72	155	24	6.1	3,160	3,840	2,640	2,460	3,790 (144)	--------	4,560 (185)
140	14	do	.64	24	--------	48 24	155 212	24	6.1	3,190	3,890	2,730	2,570	3,790 (139)	--------	5,040 (196)
141	14	do	.64	24	--------	24 48	155 212	24	6.1	3,360	3,800	3,020	2,700	3,670 (121)	--------	4,920 (182)
147	14	do	.62	24	27	--------	--------	--------	6.3	4,560	4,890	4,560	3,460	5,220 (114)	[1] 6,410	4,460 (129)
148	14	do	.62	72	--------	--------	--------	25	7.0	5,020	4,810	5,310	3,710	5,960 (112)	[1] 6,300	6,230 (168)
149	14	do	.62	24	--------	48	100	25	6.5	5,370	5,510	5,240	2,650	5,450 (104)	[1] 5,300	5,330 (201)
150	14	do	.62	24	--------	48	155	25	6.2	3,360	3,870	--------	2,640	3,400	[1] 4,060	3,690 (140)
151	14	do	.62	24	--------	48	212	25	6.1	3,300	3,750	2,840	2,660	3,650 (129)	[1] 4,110	4,090 (154)
152	14	do	.62	24	20	--------	--------	344	6.3	4,570	5,040	5,100	3,780	5,040 (99)	--------	6,240 (165)
153	14	do	.62	24	20	--------	--------	56	6.5	4,830	4,910	5,120	3,690	6,280 (123)	--------	6,720 (182)
154	14	do	.62	24	20	--------	--------	28	6.5	4,760	4,850	5,450	3,380	5,620 (103)	--------	6,460 (191)
155	14	do	.62	24	20	--------	--------	14	6.5	4,250	4,960	4,570	3,590	5,770 (126)	--------	6,420 (179)
156	14	do	.62	24	20	--------	--------	--------	6.3	4,710	4,860	4,380	3,160	4,960 (113)	--------	4,390 (139)
132	14	do	.65	24	--------	48	155	25	8.1	2,250	2,910	2,760	2,830	2,790 (101)	[1] 2,930	2,940 (104)
133	14	do	.65	24	--------	24 24	155 212	25	8.0	2,280	2,680	2,080	2,690	2,900 (139)	[1] 3,140	2,840 (106)
134	14	do	.65	24	--------	72	155	24	8.0	2,470	2,850	2,440	2,640	2,840 (116)	[1] 3,120	3,090 (117)
135	14	do	.65	24	--------	48 24	155 212	24	7.8	2,620	2,960	2,650	2,910	2,590 (98)	[1] 2,930	3,340 (115)
136	14	do	.65	24	--------	24 48	155 212	24	7.8	2,550	2,930	2,630	2,650	2,580 (98)	[1] 3,170	3,030 (114)
142	14	do	.63	24	27	--------	--------	--------	8.7	2,910	3,600	3,590	2,240	4,060 (113)	--------	3,640 (162)
143	14	do	.63	72	--------	--------	--------	25	9.3	4,220	4,430	4,220	2,160	4,310 (102)	--------	5,880 (272)
144	14	do	.63	24	--------	48	100	25	9.1	4,320	4,640	3,750	1,880	4,490 (120)	--------	4,120 (219)

[1] 2-year tests.

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TABLE 24.—*Tests of 2 by 4 inch cylinders made of high alumina cements cured in water and water vapor and exposed to the action of sulphate waters of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

Series	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Average compression tests (pounds per square inch): Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: 3 years	Lake specimens: 5 years
				Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*							
145	14	Alumina Ac1	0.63	24	--------	48	155	25	8.1	2,200	2,760	2,780	2,930	2,620 (94)	--------	3,760 (128)
146	14	do	.63	24	--------	48	212	25	7.8	2,500	2,870	2,500	2,400	3,010 (120)	--------	3,960 (165)
208–212	25	Alumina Ac3	.51	24	20	--------	--------	35	4.9	6,700	6,780	6,260	7,770	7,420 (118)	7,240	8,950 (115)
[2] 3 276	27	do	.44	24	20	--------	--------	35	6.3	6,210	7,680	6,490	6,390	8,000 (123)	7,370	7,970 (125)
[2] 277–278	27	do	.59	24	20	--------	--------	35	8.3	5,050	4,830	5,110	3,640	5,560 (109)	5,350	5,690 (156)
[2] 4 279	27	do	.73	24	20	--------	--------	35	10.2	3,380	3,090	3,250	2,380	3,730 (115)	3,350	3,830 (161)
[2] 5 280	27	do	.99	24	20	--------	--------	35	11.8	2,160	1,920	1,680	1,130	700 (42)	0	0
[3] 286	27	do	.44	24	20	--------	--------	35	5.1	7,490	6,820	8,080	8,100	8,460 (105)	8,080	8,210 (101)
287–288	27	do	.53	24	20	--------	--------	35	4.9	7,080	6,620	8,160	6,880	8,210 (101)	6,710	7,830 (114)
[4] 289	27	do	.67	24	20	--------	--------	35	5.3	6,560	5,680	6,290	4,090	6,160 (98)	5,460	6,310 (154)
[5] 290	27	do	.81	24	20	--------	--------	35	5.8	4,640	4,840	4,150	2,520	5,080 (122)	4,080	4,770 (189)
396	70, 71	do	.44	24	20	--------	--------	35	5.6	5,300	5,760	6,110	4,040	5,780 (95)	6,040	5,920 (147)
397	70, 71	do	.53	24	20	--------	--------	35	4.9	6,660	7,120	8,100	7,040	7,580 (94)	8,660	7,710 (110)
398	70, 71	do	.59	24	20	--------	--------	35	5.3	6,890	7,210	8,630	6,280	7,390 (86)	8,300	6,780 (108)
399	70, 71	do	.73	24	20	--------	--------	35	6.3	5,950	5,710	6,440	3,700	5,400 (84)	6,690	5,790 (156)
400	70, 71	do	.88	24	20	--------	--------	35	7.6	5,140	4,230	3,480	2,550	3,790 (109)	2,950	3,200 (125)
[2] 429	70, 71	do	.35	24	20	--------	--------	35	9.7	9,460	8,420	10,440	6,620	9,330 (89)	10,160	8,510 (129)
435	70, 71, 74	Alumina Ac3, 5 per cent; Portland A, 47.5 per cent; Portland B1, 47.5 per cent	.66	24	20	--------	--------	35	6.3	2,630	3,880	5,490	5,970	4,100 (75)	0	0
436	70, 71, 74	Alumina Ac3, 10 per cent; Portland A, 45 per cent; Portland B1, 45 per cent	.66	24	20	--------	--------	35	6.2	2,260	3,760	4,820	5,420	2,720 (56)	0	0
437	70, 71, 74	Alumina Ac3, 20 per cent; Portland A, 40 per cent; Portland B1, 40 per cent	.66	24	20	--------	--------	35	7.0	1,360	2,830	3,640	3,060	3,320 (91)	0	0
438	70, 71	Alumina Ac3	.66	24	20	--------	--------	35	5.8	7,080	7,790	7,820	6,440	7,220 (92)	8,130	7,810 (121)
252–253	58	Alumina Ac2	.53	24	20	--------	--------	35	5.4	7,730	7,230	7,480	4,030	7,010 (94)	7,230	7,340 (182)
[5] 291	58	do	.79	24	20	--------	--------	35	6.5	4,360	4,630	2,910	2,190	4,370 (150)	3,330	3,410 (156)
[2] 254–255	58	do	.60	24	20	--------	--------	35	9.3	5,010	4,850	2,920	2,020	4,340 (149)	3,690	3,170 (157)
[2] 5 292	58	do	.90	24	20	--------	--------	35	12.3	2,130	1,820	1,130	1,230	920 (81)	0	0

[2] Standard Ottawa sand cylinders. [3] Mix 1 : 2. [4] Mix 1 : 4. [5] Mix 1 : 5.

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Solutions of 1 per cent sodium sulphate, in which cylinders of Ac1 and Ac3 cements were stored in the laboratory, afforded a test of alumina cement much more severe than did Medicine Lake water which contained several times as much sulphate. (Table 3.) It becomes evident, however, by comparing the strength curves of cylinders stored in solutions of sodium sulphate with the curves of those in tap water (figs. 18 and 19), that only about one-half the loss in strength of the cylinders in the solutions was directly attributable to sulphate action, the remaining loss being due to temperature conditions of the laboratory as discussed on page 50. It appears, therefore, that alumina-cement cylinders normally weaken in tap water in the laboratory and that this weakening is considerably accelerated when sulphate action is introduced.

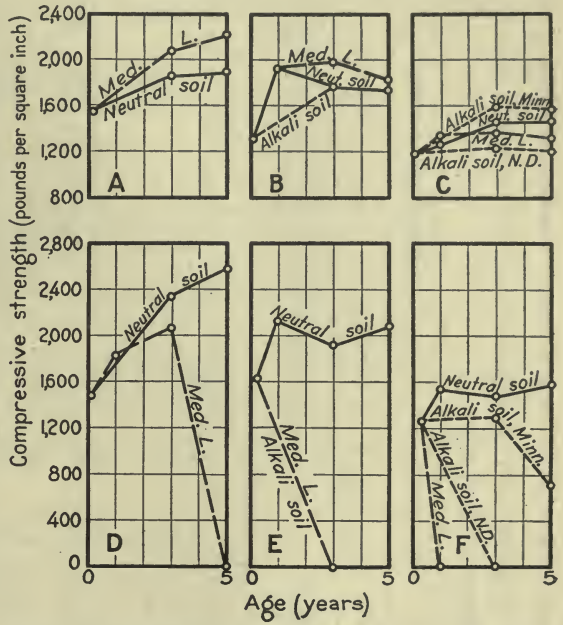

FIGURE 22.—Breaking tests up to five years of 5 and 6 inch concrete draintile made of alumina and Portland cements, exposed in Medicine Lake, S. Dak., in a neutral soil, and in alkali soils: A and B, Tile of alumina cement Ac3 and Wisconsin aggregate; C, tile of alumina cement Ac3 and Minnesota aggregate; D and E, Portland cement M and Wisconsin aggregate; F, Portland cement B and Minnesota aggregate. Each point is the average for 5 to 10 tile

Draintile of 5 and 6 inch diameters made of Ac3 cement at two commercial plants were tested for resistance under field-exposure conditions in comparison with Portland-cement tile that were essentially similar except that they were mixed 1:3 whereas the alumina-cement tile were mixed 1:4. General conditions of exposure and strength tests of the tile up to five years are recorded in Table 25 and test trends are shown in Figure 22. Both tabulated data and graphs clearly indicate a much higher degree of resistance for the tile of alumina cement than for those of Portland cement, fully supporting the results obtained in field tests of cylinders.

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TABLE 25.—*Tests up to 5 years of drain tile made of alumina and Portland cements and subjected to various conditions of exposure*

[The neutral Minnesota and Wisconsin soils were very low in soluble salts, containing, respectively, but 0.04 and 0.05 per cent]

WISCONSIN AGGREGATE

Location and exposure conditions					Strength and absorption tests							
Installation	Salt content		Mix	Tile tested	1 to 4 months		1 year		3 years		5 years	
	Lake and soil waters	Reacting values SO_4			Strength	Absorption	Strength	Absorption	Strength	Absorption	Strength	Absorption
	Parts per million	*Per cent*		*Number*	*Pounds per lin. ft.*	*Per cent*	*Pounds per lin. ft.*	*Per cent*	*Pounds per lin. ft.*	*Per cent*	*Pounds per lin. ft.*	*Per cen*
Alumina cement Ac3: [1]												
Stock pile (2 months)			1:4	8	1,540	9.3						
Stock pile (3 months)			1:4	5	1,560	8.5						
Neutral soil, Wisconsin			1:4	5					1,850	7.9	1,890	8.3
Medicine Lake, S. Dak	47,901	48.08	1:4	5					2,080	7.0	2,220	7.0
Portland cement M: [2]												
Stock pile (1 month)			1:3	8	1,210	9.2						
Stock pile (2 months)			1:3	5	1,480	9.1						
Neutral soil, Wisconsin			1:3	5					2,350	7.4	2,570	7.7
Medicine Lake, S. Dak	47,901	48.08	1:3	5			1,830	7.4	2,070	6.8	0	
Alumina cement Ac3: [3]												
Stock pile (1 month)			1:4	10	1,310	9.6						
Neutral soil, Minnesota			1:4	5			1,920	9.1	1,780	9.1	1,740	9.0
Alkali soil, North Dakota	86,386	45.70	1:4	5					1,760	8.4	1,750	8.1
Medicine Lake, S. Dak	47,901	48.08	1:4	5			1,930	8.6	1,980	7.5	1,830	8.9
Portland cement M: [4]												
Stock pile (3 months)			1:3	10	1,620	9.4						
Neutral soil, Minnesota			1:3	5			2,120	9.4	1,920	7.9	2,080	8.1
Alkali soil, North Dakota	86,386	45.70	1:3	5					0		0	
Medicine Lake, S. Dak	47,901	48.08	1:3	5			1,130	9.5	0		0	

MINNESOTA AGGREGATE

Alumina cement Ac3: [5]												
Stock pile (1 month)			1:4	10	1,180	10.4						
Neutral soil, Minnesota			1:4	5			1,270	9.4	1,460	9.1	1,470	9.1
Alkali soil, Minnesota	21,630	48.36	1:4	5					1,580	9.0	1,570	9.6
Alkali soil, North Dakota	86,386	45.70	1:4	5					1,230	8.2	1,200	8.8
Medicine Lake, S. Dak	47,901	48.08	1:4	5			1,350	9.1	1,360	8.4	1,320	9.2

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Portland cement B1: [6]												
Stock pile (4 months)			1:3	10	1,260	10.1						
Neutral soil, Minnesota			1:3	5			1,540	9.0	1,480	8.5	1,590	8.9
Alkali soil, Minnesota	21,630	48.36	1:3	5					1,290	8.6	710	9.5
Alkali soil, North Dakota	86,386	45.70	1:3	5					0		0	
Medicine Lake, S. Dak	47,901	48.08	1:3	5			0		0		0	

[1] Tile (6-inch) cured 24 hours moist room, 72 hours water vapor at 120° F., 8 weeks air.
[2] Tile (5-inch) cured 24 hours moist room, 48 hours water vapor at 120° F., 4 weeks air.
[3] Tile (5-inch) cured 24 hours moist room, sprinkled 24 hours, 3 weeks air.
[4] Tile (5-inch) cured 24 hours moist room, 48 hours water vapor at 120° F., 4 weeks air.
[5] Tile (6-inch) cured 24 hours moist room, sprinkled 2 weeks, 8 weeks air.
[6] Tile (5-inch) sprinkled 24 hours in moist room, 2 weeks air.

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MIXTURES OF ALUMINA AND PORTLAND CEMENTS

Alumina and Portland cements were mixed in various proportions to indicate the possibility of developing combinations relatively high in resistance and lower in cost than alumina cement. Results of different phases of this work are recorded in Tables 24, 26, 27, and 14. The data for series 434 in Table 14 and series 435 to 438 in Table 24 give little encouragement to this endeavor. All the cylinders containing 5, 10, and 20 per cent alumina cement and, respectively, 95, 90, and 80 per cent Portland cement, had lower strength ratios after one year in Medicine Lake than did those in which only Portland or alumina cement was used. At three years all cylinders in these series except those of 100 per cent alumina cement had failed completely.

TABLE 26.—*Effect of combining alumina cement Ac3 and Portland cement on compressive strength of concrete cylinders, normally cured and stored in tap water*

[Each test is the average of 4 or 5 cylinders made on 2 and 5 days]

Series No.	Cement		Water ratio	Absorption at 21 days	Average of compression tests					
	Alumina	Portland			1 day	3 days	7 days	28 days	1 year	5 years
	Per cent	*Per cent*		*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
381	0	100	0.64	--------	770	1,780	2,540	3,710	5,400	--------
382	5	95	.64	--------	640	1,570	2,360	3,640	4,720	--------
383	10	90	.64	--------	420	1,460	2,270	3,610	5,540	--------
384	15	85	.65	--------	390	520	1,530	3,100	5,600	--------
385	20	80	.66	--------	590	650	1,220	2,750	4,070	--------
386	25	75	.95	--------	340	440	620	1,240	1,750	--------
387	35	65	.81	--------	1,370	1,150	1,400	2,090	2,350	--------
388	50	50	.75	--------	2,300	1,790	1,410	1,760	2,720	--------
389	75	25	.69	--------	4,510	4,870	4,120	3,680	3,970	--------
390	100	0	.59	--------	6,380	6,420	7,150	7,190	7,620	--------
434	0	100	.66	6.4	--------	--------	2,590	4,080	5,050	5,830
435	5	95	.66	6.3	--------	--------	2,630	3,880	5,490	5,970
436	10	90	.66	6.2	--------	--------	2,260	3,760	4,820	5,420
437	20	80	.66	7.0	--------	--------	1,360	2,830	3,640	3,060
438	100	0	.66	5.8	--------	--------	7,080	7,790	7,820	6,440

TABLE 27.—*Effect of length changes of combining alumina cement Ac3 and Portland cement in concrete cylinders normally cured and stored in tap water*

[Each test is the average for 5 cylinders made on 5 days]

Series	Cement		Length increase at age [1]			
	Portland	Alumina	6 weeks	8 weeks	129 weeks	260 weeks
	Per cent	*Per cent*	*Inch*	*Inch*	*Inch*	*Inch*
434	100	0	−0.0017	−0.0020	−0.0007	+0.0006
435	95	5	−.0018	−.0021	−.0003	+.0008
436	90	10	−.0020	−.0023	−.0008	−.0002
437	80	20	−.0026	−.0029	−.0006	+.0002
438	0	100	−.0016	−.0019	+.0018	+.0028

[1] Initial readings made at end of three weeks.

CONCLUSION REGARDING ALUMINA-CEMENT CONCRETE AND MORTAR

Under conditions of these tests, each of three alumina cements resisted sulphate action to a high degree but was unstable when used in concrete and mortar stored for long periods in tap water at room temperatures.

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ADMIXTURES

Mixing special ingredients with Portland-cement concrete to increase resistance to sulphate attack, although long advocated and practiced, has been from the first a matter of extended controversy. That early opinions regarding admixtures were divergent is not difficult to comprehend, for there is a great range in the resistance of Portland cements from different mills as well as decided variations in the resistance of concrete due solely to variations of curing conditions, as has been discussed. Therefore, these factors had to be carefully weighed in comparing the behavior of concretes with and without admixtures, otherwise the results might be so contradictory as to be valueless or even misleading. Random comparisons based on examinations of field structures are likely to be deceiving, since exposure conditions are not identical for any two structures and may vary greatly even for different parts of the same structure. With the hope of somewhat reducing the doubts about the effect on sulphate resistance of some of the more common types of admixtures, the series of experiments here reported upon were outlined, although it was manifestly impracticable to test more than a very few of the large number of products that have been suggested.

In these experiments with admixtures 26 products were used, including 9 siliceous materials, natural and artificial; 2 high-iron products; 8 miscellaneous chemical compounds and mixtures; and 7 water-repellents, including 3 soap preparations, an organic oil, a mineral oil, kerosene, and water-gas tar. The essential chemical composition of each admixture is recorded in Table 28, and the results of fineness tests of the siliceous materials are given in Table 29. There follows a brief description of the noteworthy characteristics of the materials of each group and a summary of the observed effects on compressive strength and particularly on alkali resistance of concrete. (Tables 30 and 31, and pls. 8 and 9.) Numerous workers have reported on these and similar products used in concrete for other specific purposes (*3*, *4*, *26*, *29*, *52*).

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TABLE 28.—*Essential chemical composition of admixtures*

[Analyses by the Division of Tests, Bureau of Public Roads, U. S. Department of Agriculture, except as noted. All values are given in per cent]

Admixture	Silica (SiO_2)	Alumina (Al_2O_3) and iron (Fe_2O_3)	Metallic iron	Lime (CaO)	Magnesia (MgO)	Carbon (C)	Carbon dioxide (CO_2)	Sulphur (S)	Sulphuric anhydride (SO_3)	Sodium oxide (Na_2O)	Calcium chloride ($CaCl_2$)	Barium chloride ($BaCl_2$)	Soaps	Loss on ignition
Siliceous materials:														
Barnsdall admix	96.80	1.70												1.50
Blast-furnace slag	33.37	16.50		45.50	2.34			1.80						.27
Celite	86.40	6.90												6.70
Colloy	65.70	16.00		2.20	1.30									9.65
Fuel ash	44.50	34.00		2.80	1.14	12.70		.18	0.08					4.55
Haydite	64.35	31.70												
Omicron [1]	64.25	18.30												13.30
Trass	55.60	30.10		1.65	.90			8.00						
Volcanic ash	72.45	13.55		.70	(2)					6.02				6.10
High-iron products:														
Ironite [3]	5.25		83.33											
Metalicron [4]	10.00		90.00											
Miscellaneous chemical compounds and mixtures:														
Barium chloride (certified product) [5]												99.5		
Cal	1.58	.72		46.92	1.21				(6)		21.2			27.44
Calcium chloride (certified products) [5]											99.6			
Casein [7]														
Earthcrete [8]		.75		(2)	(2)			8.55	3.45					
Hydrated lime (high CaO) [9]														
Hydrated lime (high MgO)	1.49	.80		44.27	28.20		23.95		1.59					.57
Sulphur (certified product) [5]								100.00						
Water repellents:														
Alkagel A [10]														
Medusa waterproofing [11]													23.0	
Truscon waterproofing paste [12]													21.5	
Linseed oil [9]														
Automobile oil [9]														
Kerosene [9]														
Water-gas tar [13]														

[1] Also small amounts of lime, magnesia, and alkali salts.
[2] Trace.
[3] Iron and iron oxide equivalent to 83.33 per cent metallic iron; manganese and manganese oxide equal to 0.56 per cent metallic manganese.
[4] About 90 per cent metallic iron; balance siliceous material resembling clay.
[5] Analysis by manufacturer.
[6] None.
[7] Calcium caseinate (milk product).
[8] Unaccounted balance consisted of a mixture of sodium chloride and potassium nitrate.
[9] Not analyzed.
[10] Lost 80.87 per cent on drying; residue consisted of copper and iron soaps with paraffin; ammonia present.
[11] Soap about 23 per cent; balance was partly hydrated and carbonated lime with about 6 per cent magnesia.
[12] Water about 78 per cent; considerable free ammonia.
[13] Thin liquid with 70.09 per cent soft-pitch residue at 300° C.

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TABLE 29.—*Fineness tests of the nine siliceous admixtures for which chemical analyses are shown in Table 28*

[Analyses other than those of the 200 and 300 sieves were made by the Bureau of Standards, U. S. Department of Commerce] [1]

Admixture	Retained by No. 200 sieve	Retained by No. 300 sieve	Greater than 60 microns	Greater than 40 microns	Greater than 20 microns	Greater than 10 microns
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Barnsdall admix	0.2	0.5	----------	(2)	38.2 (21)	66.0
Blast furnace slag	12.7	19.4	32.8	58.0	76.9	84.0
Celite	1.9	2.9	----------	----------	----------	----------
Colloy	10.5	18.1	26.8 (59)	40.6 (41)	71.7 (21)	83.8 (10)
Fuel ash	3.4	5.4	(2)	14.1	36.2	55.2
Haydite	3.1	6.0	11.8	27.5 (38)	52.3 (21)	68.0
Omicron	2.8	4.4	----------	(2)	33.5 (22)	85.4
Trass	28.3	32.8	33.0	45.0 (40)	69.7	79.2
Volcanic ash	6.4	11.3	----------	----------	----------	----------

[1] Note by the Bureau of Standards: Fractionations were made in an air elutriator calibrated for Portland cement which has a density of about 3.1. As the density of the admixtures differs from this value the limiting sizes of each fraction will also differ from the nominal sizes listed above, which are for Portland cement. Microscopic measurements of the limiting sizes of separation were made in some cases. The values obtained have been placed in parentheses after the per cent residue in the table. These values are averages of measurements on about 40 particles. No measurements were made on the samples of blast furnace slag and powdered fuel ash because the particles were very irregular in size and shape. When the residue was less than 10 per cent the results obtained were not reliable because the material remaining in the bulb was not sufficient for proper agitation.

[2] Less than 10 per cent.

TABLE 30.—*Effect of admixtures on resistance of 2 by 4 inch concrete cylinders exposed in the laboratory to the action of solutions of sodium sulphate (Na_2SO_4)*

[Cements A and B1 mixed in equal portions. Each test result is the average for 5 or more cylinders made on 5 days]

Series	General description	Fineness moduli	Water-cement ratios	Absorption at 21 days	Stored in tap water		Stored in 1 per cent solutions of Na_2SO_4			
					Age tested	Breaking strengths	Age tested	Breaking strengths	Percentage of normal strength	Time required to increase in length 0.010 inch
				Per cent	*Weeks*	*Lbs. per sq. in.*	*Weeks*	*Lbs. per sq. in.*	*Per cent*	*Weeks*
51	Check cylinders without admixture.	4.67	0.59	5.1	1 4 46	3,200 4,760 5,490 (100)	46	1,860	34	43.4
52	1½ per cent Alkagel.	4.67	.60	5.7	1 4 34	2,990 4,150 5,660 (100)	34	1,600	28	31.0
53	3 per cent Alkagel.	4.67	.63	5.9	1 4 28	3,300 4,070 4,660 (100)	28	1,610	35	25.0
61	Check cylinders without admixture.	4.67	.59	5.5	1 4 38	3,430 4,290 6,130 (100)	38	1,970	32	35.4
62	5 per cent blast-furnace slag.	4.67	.60	5.4	1 4 43	3,370 4,920 6,440 (100)	43	1,900	30	40.0
63	10 per cent blast-furnace slag.	4.67	.62	5.6	1 4 59	3,110 4,710 6,200 (100)	59	1,410	23	55.7
64	20 per cent blast-furnace slag.	4.67	.65	5.6	1 4 70	3,460 4,600 6,650 (100)	70	1,720	26	67.1
65	40 per cent blast-furnace slag.	4.67	.71	5.5	1 4 49 182	3,230 4,340 7,170 (100) 7,350 (100)	49 182	3,890 2,230	54 30	178.6
46	Check cylinders without admixture.	4.67	.59	5.6	1 4 48	3,090 4,620 5,880 (100)	48	1,570	27	44.7

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TABLE 30.—*Effect of admixtures on resistance of 2 by 4 inch concrete cylinders exposed in the laboratory to the action of solutions of sodium sulphate (Na_2SO_4)*—Con.

[Cements A and B1 mixed in equal portions. Each test result is the average for 5 or more cylinders made on 5 days]

Series	General description	Fineness moduli	Water-cement ratios	Absorption at 21 days	Stored in tap water		Stored in 1 per cent solutions of Na_2SO_4			
					Age tested	Breaking strengths	Age tested	Breaking strengths	Percentage of normal strength	Time required to increase in length 0.010 inch
				Per cent	*Weeks*	*Lbs. per sq. in.*	*Weeks*	*Lbs. per sq. in.*	*Per cent*	*Weeks*
50	4 per cent cal	4.67	0.59	6.2	1 4 62	2,950 4,200 5,840 (100)	62	1,510	26	59.0
46	Check cylinders without admixture.	4.67	.59	5.6	1 4 48	3,090 4,620 5,880 (100)	48	1,570	27	44.7
49	4 per cent calcium chloride.	4.67	.61	7.0	1 4 69	2,720 3,970 4,790 (100)	69	2,480	52	66.0
56	Check cylinders without admixture.	4.67	.59	5.8	1 4 40	3,370 4,590 6,630 (100)	40	1,630	25	37.1
57	5 per cent hydrated lime, high calcium.	4.67	.61	6.0	1 4 33	3,520 4,510 5,680 (100)	33	1,760	31	30.3
58	10 per cent hydrated lime, high calcium.	4.67	.63	6.7	1 4 29	2,860 4,440 5,640 (100)	29	1,540	27	26.3
59	5 per cent hydrated lime, high magnesium.	4.67	.61	5.9	1 4 34	3,170 4,620 6,490 (100)	34	1,770	27	30.9
60	10 per cent hydrated lime, high magnesium.	4.67	.63	6.3	1 4 32	3,050 4,980 5,000 (100)	32	1,670	33	29.3
46	Check cylinders without admixture.	4.67	.59	5.6	1 4 48	3,090 4,620 5,880 (100)	48	1,570	27	44.7
47	5 per cent ironite	4.67	.59	5.8	1 4 54	3,040 4,910 5,850 (100)	54	1,560	27	50.7
48	20 per cent ironite	4.67	.61	6.2	1 4 61	3,030 4,130 5,380 (100)	61	1,590	30	58.0
41	Check cylinders without admixture.	4.67	.59	5.9	1 4 44	2,690 4,540 5,840 (100)	44	1,410	24	40.6
42	2½ per cent volcanic ash.	4.67	.61	6.4	1 4 32	2,370 4,420 4,990 (100)	32	1,440	29	28.6
43	5 per cent volcanic ash.	4.67	.63	6.2	1 4 33	2,440 4,020 5,480 (100)	33	1,730	32	30.0
44	10 per cent volcanic ash.	4.67	.65	6.3	1 4 49	2,050 3,630 5,240 (100)	49	1,700	32	45.6
45	20 per cent volcanic ash.	4.67	.74	7.0	1 4 52	1,780 3,290 5,050 (100)	52	----------	--------	[1] 267.2
51	Check cylinders without admixtures.	4.67	.59	5.1	1 4 46	3,200 4,760 5,490 (100)	46	1,860	34	43.4
54	5 per cent water-gas tar.	4.67	.55	4.7	1 4 31	2,420 3,980 4,520 (100)	31	1,590	35	28.1
55	20 per cent water-gas tar.	4.67	.51	5.7	1 4 69	1,140 2,140 2,270 (100)	69	1,140	50	65.8

[1] Estimated.

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TABLE 31.—*Tests of 2 by 4 inch concrete cylinders containing various admixtures, cured by different processes and exposed to action of sulphate waters of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions is an average of five cylinders made on different days. Figures in parenthesis, in compression test columns, indicate per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water in the laboratory]

Series	Cement laboratory No.	Portland cement	Water ratio	Admixture		Curing method					Absorption at 21 days	Average compression tests (pounds per square inch)						
												Tank specimens				Lake specimens		
				Amount	Ingredient	Time in moist closet	Time in water	Time in water vapor	Temperature of water vapor	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
				Per cent		*Hours*	*Days*	*Hours*	*°F.*	*Days*	*Per cent*							
182	18	½A and ½B1	0.59		None	24	20			35	6.0	2,800	4,010	5,780	5,790	4,450 (77)	[1] 2,100	0
183	18	do	.63	3	Alkagel A	24	20			35	5.3	2,260	3,560	4,570	4,670	3,520 (77)	[1] 2,140	0
184	18	do	.59		None	24		48	155	35	6.0	4,070	4,530	5,100	6,110	4,240 (83)	[1] 4,700	800 (13)
185	18	do	.63	3	Alkagel A	24		48	155	35	5.0	3,280	3,940	4,570	5,050	3,300 (72)	[1] 3,900	1,090 (22)
186	18	do	.63	3	do	24		48	100	35	5.4	3,120	3,730	3,820	4,420	3,550 (93)	[1] 3,060	0
554	129	do	.64		None	24	20			35	6.3	3,570	4,760	5,980	6,820	3,530 (59)	0	0
581	129	do	.62	6	Barium chloride	24	20			35	6.5	3,530	4,570	5,870	6,220	3,730 (64)	0	0
582	129	do	.62	12	do	24	20			35	6.7	3,240	4,460	5,100	6,050	4,420 (87)	2,800	0
822	225	do	.62		None	24	20			35	5.3	3,220	5,230	6,250		3,800 (61)	0	0
823	225	do	.62	3.75	Barnsdall admix	24	20			35	5.2	3,440	4,660	7,090		3,050 (43)	0	0
824	225	do	.64	7.5	do	24	20			35	5.5	2,970	5,070	6,480		3,000 (46)	0	0
825	225	do	.72	15	do	24	20			35	6.0	3,060	4,490	5,350		2,130 (40)	0	0
826	225	do	.79	30	do	24	20			35	6.8	2,310	3,790	5,410		1,450 (27)	0	0
[2] 981	263	do	.64		None	24	27			28	5.9		5,440	7,100		5,030 (71)		
[2] 982	263	do	.67	4	Barnsdall admix	24	27			28	6.1		5,630	6,610		4,590 (69)		
[2] 983	263	do	.69	6	do	24	27			28	6.0		5,140	6,050		4,060 (67)		
[2] 984	263	do	.71	8	do	24	27			28	6.1		5,560	5,950		3,800 (64)		
[2] 985	274	I	.64		None	24	27			28	5.9		5,330	7,190		7,170 (100)		
[2] 986	274	do	.67	4	Barnsdall admix	24	27			28	6.0		5,370	7,890		6,170 (78)		
[2] 987	274	do	.69	6	do	24	27			28	6.1		5,480	7,680		5,460 (71)		
[2] 988	274	do	.71	8	do	24	27			28	6.3		5,310	7,080		6,610 (93)		
[3] 989	263	½A and ½B1	.80		None	24	27			28	6.2		4,850	5,540		1,570 (28)		
[3] 990	263	do	.82	4	Barnsdall admix	24	27			28	6.6		5,010	5,770		630 (11)		
[3] 991	263	do	.83	6	do	24	27			28	6.4		4,770	5,340		980 (18)		
[3] 992	263	do	.84	8	do	24	27			28	6.2		4,660	6,050		570 (9)		
[3] 993	274	I	.80		None	24	27			28	6.5		3,980	6,610		3,970 (60)		
[3] 994	274	do	.82	4	Barnsdall admix	24	27			28	6.4		4,740	6,540		4,650 (71)		
[3] 995	274	do	.83	6	do	24	27			28	6.8		4,440	5,990		4,850 (81)		
[3] 996	274	do	.84	8	do	24	27			28	6.6		4,500	6,010		4,260 (71)		
[4] 997	263	½A and ½B1	.94		None	24	27			28	6.7		3,640	4,370		2,840 (65)		

[1] 2-year tests.
[2] Special high-silica aggregate, 1 : 3 mix; 2 by 4 inch cylinders cured in damp sand.
[3] Special high-silica aggregate, 1 : 2 : 3 mix; 2 by 4 inch cylinders cured in damp sand.
[4] Special high-silica aggregate, 1:2:4 mix; 4 by 8 inch cylinders cured in damp sand.

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TABLE 31.—*Tests of 2 by 4 inch concrete cylinders containing various admixtures, cured by different processes and exposed to action of sulphate waters of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

Series	Cement laboratory No.	Portland cement	Water ratio	Admixture		Curing method					Absorption at 21 days	Average compression tests (pounds per square inch)						
												Tank specimens				Lake specimens		
				Amount	Ingredient	Time in moist closet	Time in water	Time in water vapor	Temperature of water vapor	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
				Per cent		*Hours*	*Days*	*Hours*	*°F.*	*Days*	*Per cent*							
[4] 998	263	½A and ½B1	0.95	4	Barnsdall admix	24	27			28	6.8		3,570	4,640		2,700 (58)		
[4] 999	263	do	.96	6	do	24	27			28	6.9		4,020	4,510		1,510 (33)		
[4] 1,000	263	do	.97	8	do	24	27			28	6.9		3,610	4,650		830 (18)		
[4] 1,001	274	I	.94		None	24	27			28	6.5		3,370	4,880		4,360 (89)		
[4] 1,002	274	do	.95	4	Barnsdall admix	24	27			28	6.6		3,480	4,730		4,080 (86)		
[4] 1,003	274	do	.96	6	do	24	27			28	6.6		3,560	4,360		3,950 (91)		
[4] 1,004	274	do	.97	8	do	24	27			28	6.7		3,570	4,780		5,020 (105)		
157	18	½A and ½B1	.74	40	Blast furnace slag	24	20				6.5	2,420	3,960	6,030	6,200	4,230 (70)	[1] 2,340	0
158	18	do	.63	10	do	24	20			35	6.0	2,880	4,180	5,440	6,260	5,170 (95)	[1] 3,930	0
159	18	do	.74	40	do	24	20			35	6.7	2,410	4,190	5,670	5,600	5,560 (98)	[1] 5,220	690 (12)
160	18	do	.63	10	do	24		48	155	35	6.4	3,850	4,010	5,300	4,060	4,800 (91)	[1] 3,540	0
161	18	do	.74	40	do	24		48	155	35	6.9	3,800	4,020	5,450	5,710	4,830 (89)	[1] 5,640	2,760 (48)
172	18	do	.59		None	24	20			35	5.6	2,870	4,190	5,300	5,400	4,370 (82)	[1] 2,050	0
167	18	do	.59	4	Cal	24	20				5.7	3,200	4,150	4,860	5,600	3,910 (80)	[1] 1,380	0
168	18	do	.60	8	do	24	20			35	5.8	3,180	4,290	5,570	6,370	4,620 (83)	[1] 3,690	1,570 (25)
169	18	do	.59	4	do	24	20			35	5.8	3,250	4,280	4,550	5,580	4,800 (105)	[1] 3,620	1,090 (20)
170	18	do	.60	8	do	24		48	155	35	6.0	4,990	4,670	5,030	5,960	5,010 (100)	[1] 6,200	5,540 (93)
171	18	do	.59	4	do	24		48	155	35	6.0	4,550	4,690	5,140	5,730	4,980 (97)	[1] 5,560	4,690 (82)
172	18	do	.59		None	24	20			35	5.6	2,870	4,190	5,300	5,400	4,370 (82)	[1] 2,050	0
162	18	do	.63	4	Calcium chloride	24	20				5.7	2,870	4,330	5,530	5,130	3,910 (71)	[1] 1,710	0
163	18	do	.79	8	do	24	20			35	7.1	2,200	3,010	4,280	4,220	3,550 (83)	[1] 3,130	1,040 (25)
164	18	do	.63	4	do	24	20			35	5.9	2,940	4,000	5,450	5,790	5,050 (93)	[1] 5,240	2,200 (38)
165	18	do	.79	8	do	24		48	155	35	7.1	3,800	3,640	4,600	4,620	3,300 (72)	[1] 3,860	3,770 (82)
166	18	do	.63	4	do	24		48	155	35	5.8	4,840	4,920	4,990	5,970	4,460 (89)	[1] 5,840	4,990 (84)
172	18	do	.59		None	24	20			35	5.6	2,870	4,190	5,300	5,400	4,370 (82)	[1] 2,050	0
1181	294	do	.62		do	24	20			35	5.8	4,930	6,580	6,420		3,540 (55)		
1182	294	do	.62	⅛	Casein	24	20			35	6.3	4,300	5,030	6,620		3,170 (48)		
1183	294	do	62	¼	do	24	20			35	7.0	4,020	5,050	5,720		3,250 (57)		
1184	294	do	.62	½	do	24	20			35	6.7	3,870	4,760	5,480		3,440 (63)		
1185	294	do	.62	1	do	24	20			35	7.9	2,490	3,680	4,290		2,660 (62)		
412	105	Q2	.66	2½	Celite	24	20			35	6.4	3,530	5,050	6,670	6,280	3,760 (56)	0	0
413	105	do	.62		None	24	20			35	5.7	3,520	5,390	6,500	6,350	4,300 (66)	0	0
583	139	½A and ½B1	.62		do	24	20			35	6.3	3,810	4,950	6,420	7,820	3,650 (57)	0	0
634	139	do	.64	2	Celite	24	20			35	6.1	3,260	5,340	6,180	6,390	5,290 (86)	0	0
635–636	139	do	.64		None	24		48	212	53	6.3	3,960	4,330	4,250	6,600	4,370 (103)	5,950	6,530 (99)

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637–638	139	do	.64	2	Celite	24		48	212	53	6.2	4,160	4,730	5,300	6,910	4,410 (83)	5,020	6,250 (90)
639	139	do	.64	2	Colloy	24	20			35	6.5	3,630	4,610	5,250	5,800	4,630 (88)	0	0
640	139	do	.64		None	24	20			35	6.5	3,320	4,470	5,800	6,070	4,530 (78)	0	0
641	139	do	.64		do	24		48	212	53	6.9	3,590	3,760	4,530	6,010	3,740 (83)	5,360	6,140(102)
642–643	139	do	.64	2	Colloy	24		48	212	53	6.8	3,870	4,100	4,420	6,270	3,800 (86)	5,510	5,840 (93)
776	204	do	.62		None	24	20			35	6.2	3,400	4,420	6,480		0	0	0
777	204	do	.64	2	Colloy	24	20			35	6.4	3,160	4,640	5,270		0	0	0
778	204	do	.65	4	do	24	20			35	6.4	3,200	4,540	6,110		0	0	0
715	176	do	.62		None	24	20			35	5.6	3,830	5,100	6,420		4,550 (71)	0	0
716	176	do	62	.27	Earthcrete	24	20			35	5.6	4,460	5,160	5,780		4,630 (80)	0	0
717	176	do	.62	1.06	do	24	20			35	5.8	3,530	5,120	6,950		4,860 (70)	0	0
718	176	do	.62	.27	do	24		48	155	53	5.6	5,210	5,550	5,370		5,150 (96)	0	0
554	129	do	.64		None	24	20			35	6.3	3,570	4,760	5,980	6,820	3,530 (59)	0	0
564–565	129	do	.62	2½	Fuel ash	24	20			35	6.3	3,580	5,100	6,710	7,410	2,840 (42)	0	0
566	129	do	.64	5	do	24	20			35	6.4	3,300	4,760	5,850	7,260	2,670 (46)	0	0
567–568	129	do	.67	10	do	24	20			35	6.3	3,390	5,080	6,570	6,370	3,660 (56)	0	0
[5] 1186	295	A	.77		None	24	27				8.2	2,410	3,790	4,290		1,870 (44)		
[6] 1187	295	do	1.13	43	Haydite	24	27				9.0	1,680	3,070	5,330		3,370 (63)		
[7] 1188	295	do	2.05	150	do	24	27				10.2	690	1,760	4,460		3,170 (72)		
[5] 1189	296	Special F	.77		None	24	27				8.3	4,750	5,540	6,040		4,930 (82)		
[6] 1190	296	do	1.13	43	Haydite	24	27				8.2	3,340	4,140	5,980		4,920 (82)		
[7] 1191	296	do	2.05	150	do	24	27				11.2	1,260	2,600	4,560		2,990 (66)		
1192	294	½A and ½B1	.62		None	24	27				5.7	4,880	6,060	6,500		4,760 (73)		
[8] 1193	294	do	.90	43	Haydite	24	27				6.1	3,100	4,740	6,370		5,470 (86)		
[9] 1194	294	do	1.62	150	do	24	27				6.5	1,530	2,620	5,260		3,920 (75)		
1195	294	do	.71	30	do	24	27				5.8	4,390	5,840	7,450		6,750 (91)		
172	18	do	.59		None	24	20			35	5.6	2,870	4,190	5,300	5,400	4,370 (82)		0
173	18	do	.61	20	Ironite	24	20			35	5.9	2,950	3,980	4,890	5,800	5,020(102)		1,590 (27)
174	18	do	.59		None	24		48	155	35	6.1	4,020	4,390	4,330	5,650	3,910 (90)		2,740 (48)
175	18	do	.61	20	Ironite	24		48	155	35	6.1	3,880	4,440	5,510	5,630	4,630 (84)		5,280 (94)
176	18	do	.61	20	do	24		48	100	35	6.1	3,680	4,220	5,250	5,770	5,190 (99)		5,020 (87)
1141	287	do	.62		None	24	20			35	5.6	4,560	5,400	7,160		4,440 (62)		
1142	287	do	.62	1	Kerosene	24	20			35	5.3	3,930	5,760	6,160		3,230 (52)		
1143	287	do	.62	2	do	24	20			35	5.1	3,790	5,740	5,940		3,850 (65)		
1144	287	do	.62	4	do	24	20			35	4.4	3,800	5,530	5,930		3,350 (56)		
1145	287	do	.62	8	do	24	20			35	4.8	3,740	4,870	5,520		2,670 (48)		
1156	294	do	.62		None	24	20			35	5.9	4,670	5,400	5,900		2,250 (38)		
1157	294	do	.62	½	Linseed oil	24	20			35	4.5	3,910	5,700	6,100		3,330 (55)		
1158	294	do	.62	1	do	24	20			35	3.6	4,240	5,470	5,350		4,190 (78)		
1159	294	do	.62	2	do	24	20			35	3.5	3,120	4,550	5,660		5,050 (89)		
1160	294	do	.62	4	do	24	20			35	3.1	1,820	3,970	5,100		4,960 (97)		
769	201	X	.62		None	24	20			35	6.3	3,050	4,960	6,440		4,440 (69)	0	0
770	201	X	.62	2	Medusa waterproofing.	24	20			35	5.0	3,220	4,750	5,930		3,020 (51)	0	0
779	201	X	.62	1	do	24	20			35	5.2	3,030	4,690	5,480		25,70 (50)	0	0

[3] Special high-silica aggregate, 1 : 2 : 3 mix; 2 by 4 inch cylinders cured in damp sand.
[4] Special high-silica aggregate, 1 : 2 : 4 mix; 4 by 8 inch cylinders cured in damp sand.
[5] Mix 1 : 2½; special aggregate—fineness modulus 2.95.
[6] Mix 1 : 3½; special aggregate—fineness modulus 2.95.
[7] Mix 1 : 6; special aggregate—fineness modulus 2.95.
[8] Mix 1 : 4½.
[9] Mix 1 : 7½.

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TABLE 31.—*Tests of 2 by 4 inch concrete cylinders containing various admixtures, cured by different processes and exposed to action of sulphate waters of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*—Continued

Series	Cement laboratory No.	Portland cement	Water ratio	Admixture		Curing method					Absorption at 21 days	Average compression tests (pounds per square inch)						
												Tank specimens				Lake specimens		
				Amount	Ingredient	Time in moist closet	Time in water	Time in water vapor	Temperature of water vapor	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
				Per cent		*Hours*	*Days*	*Hours*	*°F.*	*Days*	*Per cent*							
780	201	X	0.65	4	Medusa waterproofing.	24	20	------	------	35	4.0	2,780	4,700	5,340	------	2,190 (41)	0	0
1196	294	½A and ½B1	.62	------	None	24	20	------	------	35	5.4	4,750	6,380	6,740	------	4,460 (66)	------	------
1197	294	do	.64	20	Metalicron	24	20	------	------	35	5.3	5,060	6,480	6,730	------	5,200 (77)	------	------
1198	294	do	.67	40	do	24	20	------	------	35	5.4	4,650	5,800	6,880	------	4,870 (71)	------	------
1199	294	do	.62	------	None	24	------	48	155	53	5.5	5,100	5,060	6,120	------	5,580 (91)	------	------
1200	294	do	.64	20	Metalicron	24	------	48	155	53	5.6	5,520	4,970	6,630	------	5,300 (80)	------	------
1146	287	do	.62	------	None	24	20	------	------	35	5.3	4,280	5,960	7,200	------	3,370 (47)	------	------
1147	287	do	.62	1	Oil	24	20	------	------	35	2.8	4,580	5,260	7,290	------	3,010 (41)	------	------
1148	287	do	.62	2	do	24	20	------	------	35	2.4	4,460	5,990	6,520	------	4,450 (68)	------	------
1149	287	do	.62	4	do	24	20	------	------	35	2.0	4,180	5,530	5,860	------	3,940 (67)	------	------
1150	287	do	.62	8	do	24	20	------	------	35	1.8	3,390	4,720	6,010	------	2,090 (35)	------	------
771	204	do	.62	------	None	24	20	------	------	35	5.9	3,450	4,440	5,870	------	0	0	0
772	204	do	.65	3.75	Omicron	24	20	------	------	35	6.1	3,510	4,480	6,010	------	0	0	0
773	204	do	.69	7.5	do	24	20	------	------	35	6.5	3,240	4,710	5,370	------	0	0	0
774	204	do	.74	15.0	do	24	20	------	------	35	7.6	3,430	4,360	5,510	------	3,440 (62)	0	0
775	204	do	.86	30.0	do	24	20	------	------	35	9.9	3,050	4,220	4,980	------	4,430 (89)	3,870	------
[10] 293	19	do	.64	------	None	24	20	------	------	35	9.9	1,420	2,240	3,850	3,740	2,140 (56)	0	0
[10] 294	19	do	.67	10	Sulphur	24	20	------	------	35	9.7	1,150	1,250	1,870	2,610	0	0	0
391	74	do	.62	------	None	24	20	------	------	35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
392	74	do	.76	33	Trass	24	20	------	------	35	7.3	2,710	3,830	5,790	5,620	5,040 (87)	2,810	1,750 (31)
[11] 392a	74	do	.85	33	do	24	20	------	------	35	7.1	2,430	3,450	5,260	5,540	4,170 (79)	2,060	1,300 (23)
393	74	do	.93	66	do	24	20	------	------	35	9.1	1,930	3,350	4,600	5,100	4,400 (96)	3,510	2,140 (42)
[12] 393a	74	do	1.09	66	do	24	20	------	------	35	8.4	1,440	2,670	4,270	4,740	3,660 (86)	2,650	1,830 (39)
394	86	I	.78	33	do	24	20	------	------	35	6.8	3,330	4,690	6,620	7,180	5,300 (80)	2,940	1,260 (18)
[11] 394a	86	I	.87	33	do	24	20	------	------	35	6.7	3,000	3,850	6,170	5,410	4,140 (67)	1,080	0
395	86	I	.95	66	do	24	20	------	------	35	7.6	2,710	3,770	6,060	4,970	4,300 (71)	2,570	2,110 (42)
[12] 395a	86	I	1.09	66	do	24	20	------	------	35	7.3	2,280	3,380	4,090	4,990	3,810 (93)	------	1,620 (32)
554	129	½A and ½B1	.64	------	None	24	20	------	------	35	6.3	3,570	4,760	5,980	6,820	3,530 (59)	0	0
578	129	do	.62	1	Truscon	24	20	------	------	35	4.7	3,370	4,700	5,320	6,490	3,750 (70)	0	0
579	129	do	.62	2	do	24	20	------	------	35	4.1	3,370	4,580	4,980	5,390	3,280 (66)	0	0
580	129	do	.62	4	do	24	20	------	------	35	3.7	3,020	3,980	4,630	5,230	2,420 (52)	0	0
177	18	do	.59	------	None	24	20	------	------	35	5.9	2,520	4,200	4,930	6,120	3,670 (74)	[1] 1,910	0
178	18	do	.74	20	Volcanic ash	24	20	------	------	35	6.8	1,900	3,210	5,450	5,670	2,960 (54)	[1] 1,970	0
179	18	do	.59	------	None	24	------	48	155	35	5.8	4,110	4,510	5,210	6,460	3,820 (73)	[1] 2,380	1,750 (27)
180	18	do	.74	20	Volcanic ash	24	------	48	155	35	7.6	3,240	3,340	4,440	5,560	3,600 (81)	[1] 4,510	1,760 (32)
181	18	do	.74	20	do	24	------	48	100	35	7.3	2,710	2,820	5,130	5,670	4,290 (84)	[1] 3,590	2,430 (43)

[10] Standard Ottawa sand cylinders. [11] Mix 1 : 4. [12] Mix 1 : 5.

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In preparing the mix for the test specimens, all admixtures were added to the batch except as otherwise noted, the proportions of the admixtures being calculated on a basis of their weight added to that of the cement in the mix.

SILICEOUS MATERIALS

Finely divided silicas of volcanic origin, diatomaceous earths, ground burned clays, ground blast-furnace slags, and similar substances, because of their pozzuolanic properties, have been used and recommended by engineers of continental Europe, for concrete exposed to sea water, and in recent years have been favorably considered by a number of English cement chemists and engineers (*12*, *19*). Engineers of the United States and Canada, however, have never generally accepted as a proven fact the practical value of siliceous admixtures. As is well known, the use of a pozzuolana is based on the theory that active silica of the admixture will slowly combine with free lime of the set cement to form relatively insoluble compounds of calcium silicate.

The chemical composition of the siliceous admixtures tested differs greatly in silica (SiO_2) content, as shown in Table 28, although blast-furnace slag with 33.37 per cent and fuel ash with 44.5 per cent were the only ones containing less than 50 per cent of silica. In the other materials the range was from 55.6 per cent for trass to 96.8 per cent for Barnsdall admix. These chemical analyses mean little when considered alone, if the theory underlying the use of siliceous admixtures is sound, since only the silica active at ordinary temperatures is of value, and that must be finely divided to combine readily with the free lime of the cement.

A completely satisfactory method for determining active silica has not been agreed upon. The method used in these experiments was that suggested by Cowper (*18*, *p. 46–49*), in which 0.6 gram of the siliceous material was combined with 0.4 gram of hydrated lime, placed in a test tube, and shaken at intervals of 12 hours. The pozzuolanic activity was judged by inspecting the tubes at different times after shaking and noting the increase in volume of the solid matter. The results are shown in Table 32. Another method has been suggested by Blount (*12*) who stated that normally the active silica is regarded as that which can be extracted from the material by a weak alkali such as 1 per cent caustic soda solution, but there is no fixed method. A third method (*24*) is based on the electric resistance, measured to 0.1 ohm, of a lime water solution of known strength to which is added the siliceous material and the pozzuolanic activity calculated on a basis of decreased conductivity due to removal of some of the lime as a result of chemically combining with active silica.

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TABLE 32.—*Pozzuolanic activity of the nine siliceous admixtures, compared by volume increase*

Days	Barnsdall admix	Blast-furnace slag	Celite	Colloy	Fuel ash	Haydite	Omicron	Trass	Volcanic ash
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	31	103	192	244	83	22	300	31	18
2	40	232	223	322	117	53	684	80	30
3	40	267	338	377	133	88	940	107	60
4	42	285	346	414	150	105	932	133	85
5	50	322	369	432	147	119	924	143	110
6	60	340	338	469	150	133	876	170	127
7	60	304	365	524	158	122	924	170	118
8	50	322	323	450	167	105	908	179	118
9	60	336	392	460	171	135	872	186	135
10	60	340	377	469	184	152	874	188	135
11	60	327	368	469	179	152	876	206	145
12	60	324	350	450	201	140	829	198	135
13	60	324	342	450	217	156	812	197	150
14	60	322	346	450	217	156	748	206	148

Of the nine siliceous admixtures tested, blast-furnace slag, trass, and volcanic ash are the only ones that definitely increased resistance. The effect of Haydite is still undetermined. It is not seen how the pozzuolanic activity recorded in Table 32 or the fineness tests of Table 29 could have been used to predict the relative effect of the siliceous materials of this group on resistance of concrete to sulphate action. Therefore, it appears that, regardless of the methods used to determine the active properties of a pozzuolana, justification for its use to increase the resistance of a Portland-cement concrete must depend upon careful experimentation.

Barnsdall admix has the appearance of pulverized chert and is described by the producers as a "pure, finely ground, meta-colloidal Tripoli silica." This product was used in quantities varying from 3.75 to 30 per cent and in 1 : 3, 1 : 2 : 3, and 1 : 2 : 4 concretes. Two aggregates, a combination of two cements of low resistance, and a resistant cement were used in the tests. It is not apparent from tests up to three years (Table 31) that this material increased resistance; some of the data seemed to indicate decreased resistance. The effect of 8 per cent and less of the admixture on the 28-day strength of concrete was small, but was slightly advantageous with the leaner mixes. The effect on the strength at one year was inappreciable. Fifteen and thirty per cent of the admixture decreased compressive strengths at 28 days and at 1 year.

Blast-furnace slag, finely ground, was used in proportions of 5 10, 20, and 40 per cent in cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate and in proportions of 10 and 40 per cent in cylinders exposed in Medicine Lake. Some of these cylinders were cured in water at room temperatures and others in water vapor at 155° F. This slag did not appreciably affect the 28-day strength of normally cured concrete. The data definitely indicate that the strength increased at one and five years for cylinders containing 10 and 40 per cent, the only ones of which long-time tests were made. Resistance to the laboratory solutions increased with quantity of slag used, the cylinders containing 40 per cent of slag having a life 400 per cent longer than the check group. Stored in Medicine Lake the normally cured cylinders containing 40 per cent slag definitely increased in resistance and the cylinders containing 10 per cent slag increased slightly. Cylinders with 40 per cent slag but with no air hardening showed little or no increased resistance, nor did cylinders containing 10 per cent slag cured at 155° F. Cyl-

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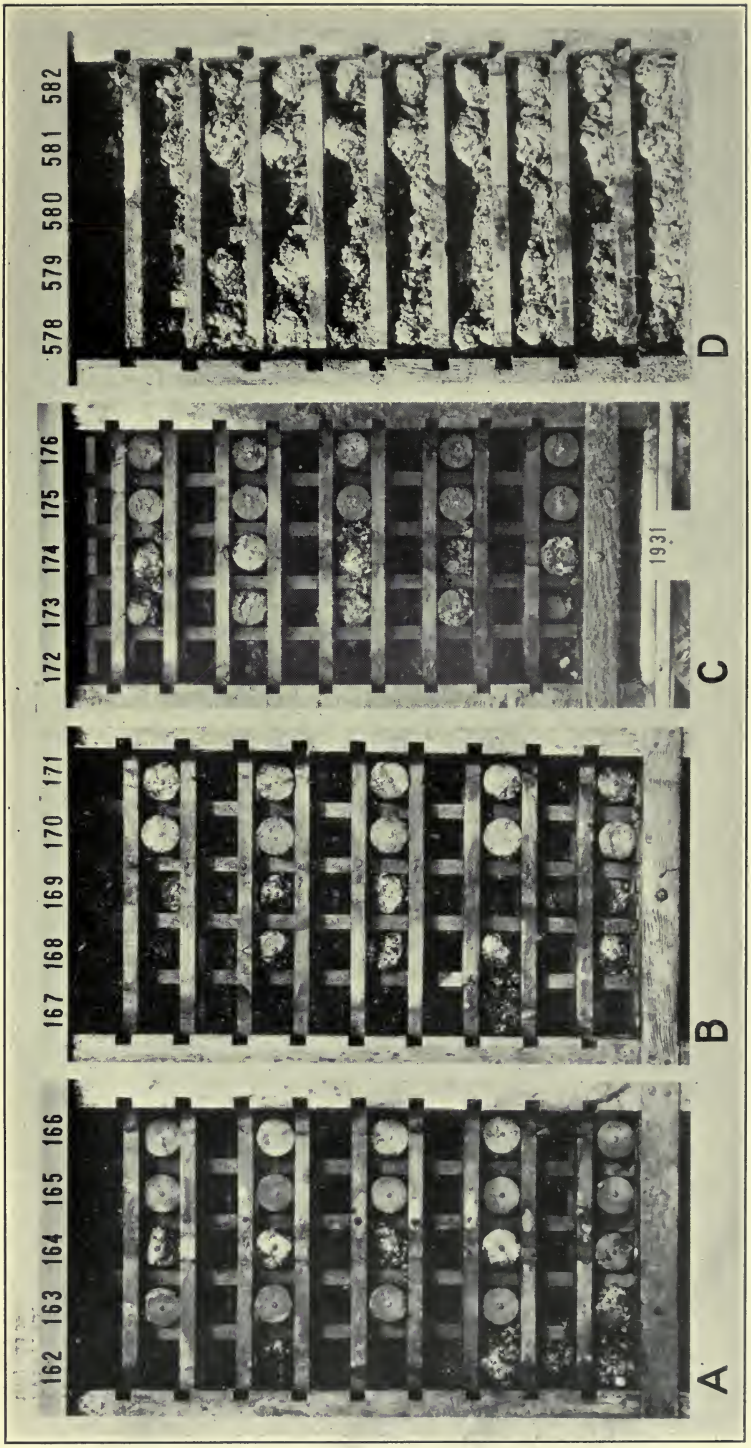

CYLINDERS CONTAINING VARIOUS ADMIXTURES AFTER STORAGE FOR SEVEN YEARS IN MEDICINE LAKE

A, Calcium chloride admixed as follows: Series 162, 164, and 166—4 per cent; series 163 and 165—8 per cent. Series 165 and 166 cured 48 hours in water vapor at 155° F. B, Cal, same treatment as in A. C, Series 172—no admixture; 173—20 per cent ironite; 174—no admixture but cured 48 hours in water vapor at 155° F.; 175—20 per cent Ironite, cured 48 hours in water vapor at 155° F.; 176—20 per cent Ironite, cured 48 hours in water vapor at 100° F. D, Series 578, 579, and 580 contained 1, 2, and 4 per cent, respectively, of Truscon waterproofing paste. Series 581 and 582 contained 6 and 12 per cent respectively, of barium chloride

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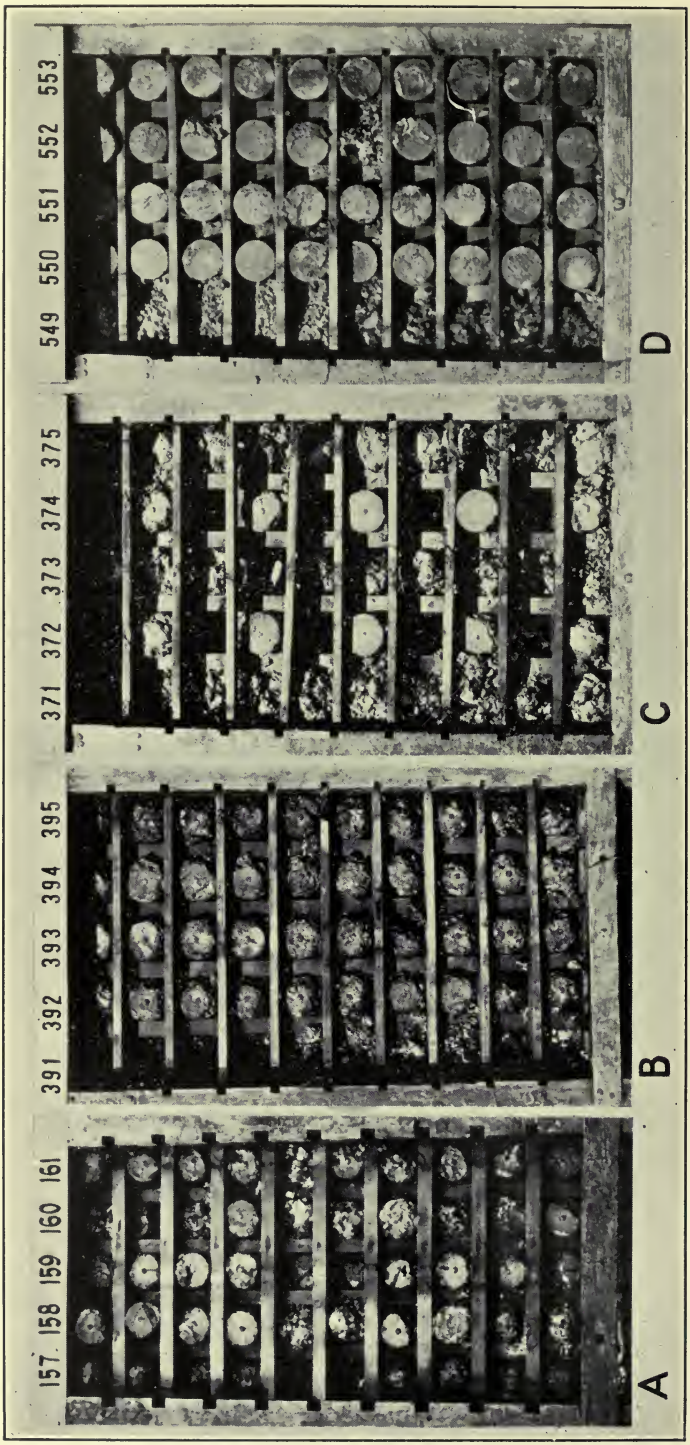

CYLINDERS CONTAINING SILICEOUS ADMIXTURES AND CYLINDERS' SURFACE TREATED, AFTER STORAGE IN MEDICINE LAKE

A, Blast-furnace slag admixed in the following percentages, after five years in the lake. Series 157, 159, and 161—40 per cent; series 158 and 160—10 per cent. Series 160 and 161 were cured 48 hours in water vapor at 155° F. B, Series 391 contained no admixture. Series 392 and 394 contained 33 per cent trass and series 393 and 395 contained 66 per cent trass. After four and one-half years in the lake. C, Series 371 to 373 standard Portland cement series 374 and 375 concrete and mortar, respectively, surface treated with Inertol. After five and one-half years in the lake. D, Series 549 to 553, respectively, surface-treated by dipping as follows, after four and one-half years in the lake; boiling water one-half minute; one coat linseed oil 70° F. one-half minute; two coats linseed oil 70°, one-half minute, one coat linseed oil 225° one-half minute; two coats linseed oil 225° one-half minute

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inders containing 40 per cent slag and cured at 155° tested 48 per cent of normal at five years, this series making considerably the best showing in Medicine Lake of any of the slag group. (Pl. 9.)

Celite, a diatomaceous earth, used in the proportions of 2 and 2½ per cent, did not appreciably affect either strength or resistance of normally cured cylinders.

Colloy, probably benonite clay, used in proportions of 2 and 4 per cent, resulted in concrete weaker at one year than check cylinders with no admixture. The effect of either quantity on strength and resistance was negligible.

Fuel ash, used in proportions of 2½, 5, and 10 per cent, apparently had no pronounced effect on the compressive strength or resistance of cylinders up to five years.

Haydite, a burned clay ground until 94 per cent passed a No. 300 sieve, was used both as a substitute for some of the cement and as an addition to the batch. This product was substituted for 30 and 60 per cent of the cement in the cylinders of most series, but 30 per cent was added to the cement for one series. As used, this material increased absorption and considerably reduced the 7 and 28 day strengths, but between 7 and 28 days there was a pick-up, so that cylinders in which 30 per cent of the cement was substituted averaged slightly stronger than the respective check cylinders and in those having 60 per cent substitution the strength recoveries were pronounced. The strongest and most resistant 1-year cylinders were those with the 30 per cent addition. (Table 31.) Tests with Haydite are being continued in a number of new series not here reported.

Omicron is the trade name for a finely divided product which was added in quantities up to 30 per cent. The effect on strength at one year was inappreciable for 3.75 per cent, but for 7.5, 15, and 30 per cent was a slight reduction. The cylinders in which 15 and 30 per cent was used showed increased resistance at one year, but no effect was indicated for 3.75 and 7.5 per cent. The only cylinders exposed in Medicine Lake that were made with this material and showed any compressive strength at three years were those containing 30 per cent admixture.

Trass, long used in hydraulic limes and cements, was imported from Germany. Trass is described by Eckel (*21*) as an ancient volcanic mud composed of earthy or compact pumiceous dust with fragments of pumice, trachyte, carbonized wood, etc. This material, finely powdered, was used both as an addition to the batch and as a substitute for some of the cement, with surprisingly similar effects on the compressive strength of the concrete for all periods up to five years. The quantities added were equivalent to 33 and 66 per cent of the weight of the cement, which by volume were almost exactly 50 and 100 per cent the volume of the cement; the quantities substituted replaced 25 and 40 per cent of the cement by weight. In both cases and at all ages, 66 per cent of trass reduced the strength of the concrete by about 25 per cent and 33 per cent reduced the strength by about half as much. The different additions increased resistance of the concrete about equally, with the result that cylinders containing trass averaged about 34 per cent of normal strength at five years, as against 0 per cent at three years, as compared with the check group without trass. While results were far from ideal, it was evident that trass did definitely increase resistance of concrete under extremely severe conditions of exposure. (Pl. 9.)

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Volcanic ash from northwestern Nebraska was added to the mix in quantities of 2.5, 5, 10, and 20 per cent for cylinders stored in 1 per cent solutions of sodium sulphate in the laboratory and 20 per cent for cylinders stored in Medicine Lake. Twenty per cent ash increased the resistance of the laboratory cylinders more than 500 per cent, but lesser quantities had very little effect. Twenty per cent ash did not, however, increase the resistance of the cylinders exposed in Medicine Lake; on the contrary, it slightly reduced their resistance. In all cases, this product reduced the compressive strength of concrete at 7 and 28 days, loss of strength being in the same proportion as quantity of admixture. The only long-time strength data are 1 and 5 year tests of cylinders with 20 per cent ash, which averaged 11 per cent stronger at one year and 7 per cent weaker at five years than did normal check cylinders. This might be interpreted in a number of ways, but has been assumed to indicate that 20 per cent of this volcanic ash had slight effect on strength beyond one year. It is evident that more tests of this product might profitably be made, as regards both its effect on resistance and its effect on long-time strength.

HIGH-IRON PRODUCTS

Ironite is the trade name for finely ground iron and iron oxide, equivalent to 83.33 per cent metallic iron, mixed with ammonium chloride to hasten oxidation when used as a brush coat. Twenty per cent of this material was added to the batch for cylinders tested in Medicine Lake and 20 and 5 per cent to cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate. Special water-vapor curing at temperatures of 100° and 155° F. was used for some of the cylinders exposed in Medicine Lake. The effect of Ironite on compressive strength of normally cured cylinders was inappreciable at all ages up to 5 years. The effect on resistance was beneficial, particularly for the cylinders cured at 100° and 155° which had respective strength ratios of 87 and 94 per cent after five years in Medicine Lake. (Pl. 8.)

Metalicron is a trade product consisting of about 90 per cent finely divided metallic iron and the balance a siliceous material resembling clay. Cylinders with 20 per cent admixture were slightly stronger at 7 and 28 days than the check cylinders, and those with 40 per cent were slightly weaker, although at one year the strengths of all cylinders were essentially similar. At one year the effect of Metalicron on resistance, while positive, was not pronounced.

MISCELLANEOUS CHEMICAL COMPOUNDS AND MIXTURES

Barium chloride, among other things, was recommended by Michaelis (*32*) as long ago as 1891 for increasing resistance of concrete in sea water. Six and 12 per cent of barium chloride dissolved in the mixing water reduced the strength of concrete at all ages up to five years, but somewhat increased the resistance to sulphate. Cylinders containing 12 per cent tested 87 per cent of normal strength after one year in Medicine Lake, and not far from 50 per cent after three years. All of the barium chloride cylinders tested in Medicine Lake, however, failed before five years.

Cal is a material obtained by pulverizing the dried or undried product resulting from a mixture of either quick lime or hydrated

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lime, calcium chloride, and water (*61*). Additions of 4 per cent of this material were used in cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate, and 4 and 8 per cent additions were used both in cylinders cured normally and in cylinders cured in water vapor at 155° F. for Medicine Lake exposure tests. The effect of 4 and 8 per cent of Cal on compressive strength was not very pronounced, although cylinders with the admixture generally tested slightly stronger than those of plain concrete. The cylinders containing 4 per cent Cal tested 14 per cent weaker than the check groups at one year, but stronger at five years. Additions of Cal increased resistance, under the conditions of the tests, except in cylinders without air hardening of one Medicine Lake series containing 4 per cent. Cylinders containing 4 and 8 per cent Cal when cured at 155° F. had the high values of 82 and 93 per cent, respectively, of normal strength at five years. (Pl. 8.)

Calcium chloride equivalent in weight to 4 and 8 per cent of the cement was dissolved in the mixing water. Four per cent was added for cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate, while 4 and 8 per cent were used in cylinders exposed in Medicine Lake, some cured normally and some cured in water vapor at 155° F. Four per cent calcium chloride had slight effect on compressive strength at any age between 7 days and 5 years, but 8 per cent reduced the strength at all ages, the average reduction being in excess of 20 per cent. The sulphate resistance of cylinders was increased by the calcium chloride in all cases except one Medicine Lake series with 4 per cent and without air hardening. Cylinders containing 4 and 8 per cent calcium chloride when cured at 155° gave the high strength ratios of 84 and 82 per cent, respectively, at five years. (Pl. 8.)

Casein, or calcium caseinate, is a finely powdered milk derivative. It was used as a concrete admixture in small quantities of 0.125, 0.25, 0.5, and 1 per cent of the weight of the cement. All quantities decidedly reduced the 7 and 28 day strengths, with 1 per cent causing reductions of more than 40 per cent. At 1 year, the effect on strength was less pronounced than at 7 and 28 days, and a very slight tendency toward increasing the resistance to sulphates was evident.

Earthcrete is the trade name of a powdered mixture consisting essentially of sodium chloride and potassium nitrate. Added in proportions of 0.27 and 1.06 per cent of the cement, it did not appreciably increase the resistance of cylinders exposed in Medicine Lake. As used, the effect on compressive strength was not pronounced at 7 days, 28 days, or 1 year.

Hydrated limes, both high-calcium and high-magnesium, behaved so similarly that in this discussion they need not be considered separately. Five and ten per cent of these limes had slight effect on compressive strengths at 7 and 28 days. The only long-time compression tests made were at ages between 32 and 43 weeks, when all cylinders containing hydrated lime showed loss of strength except those with 5 per cent high-magnesium lime which tested about normal. The effect on resistance of cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate was negative in all cases.

Sulphur used in the proportion of 10 per cent decreased compressive strength at all ages from 7 days to 5 years, and very definitely decreased the resistance of cylinders stored in Medicine Lake.

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WATER REPELLENTS

The group of water repellents includes three patented soap preparations, boiled linseed oil, automobile oil of medium viscosity, kerosene, and water-gas tar. They very generally decreased absorption of water by the concrete. Four of them, in some one or more of the quantities used, reduced the absorption by more than one-third. This effect of oils has long been known (*39*). However, it is not evident from the results obtained with these water-repellents and also with some of the other materials, that the absorption of concrete is by itself of any value whatever as an index of sulphate resistance.

Alkagel A is the trade name of a colloidal paste of copper and iron soaps together with paraffin, which smelled strongly of ammonia and lost 81 per cent of its weight on drying. Alkagel A was added to the mixing water in proportions of 1.5 and 3 per cent of the weight of the cement in cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate, while for cylinders exposed in Medicine Lake 3 per cent was used in normally cured cylinders and in cylinders cured in water vapor at 100° and 155° F. This product caused decreases in compressive strength at all ages from 7 days to 5 years except with one series which had normal strength at 7 days. The effect on sulphate resistance ranged from an inappreciable increase to a decided decrease. Curing cylinders containing this paste at 100° and 155° F. gave no positive results.

Medusa waterproofing is a powder consisting of 23 per cent soap mixed with hydrated and carbonated lime and about 6 per cent magnesia. Used in proportions of 1, 2, and 4 per cent, it caused no increase in sulphate resistance of cylinders stored in Medicine Lake, though absorption by those cylinders decreased with increase in quantity of admixture. The compressive strength was affected inappreciably at seven days and was considerably reduced at one year.

Truscon waterproofing paste, concentrated, added to the mixing water at rates of 1, 2, and 4 per cent of the weight of the cement, did not appreciably increase the resistance of any of the cylinders in which it was used, although absorption by the cylinders decreased as the quantity of admixture was increased. The effect on compressive strength ranged from inappreciable and adverse at 7 and 28 days to adverse at 1 and 5 years. (Pl. 8.)

Linseed oil, boiled, added in proportions of 0.5, 1, 2, and 4 per cent of the weight of the cement, retarded hardening, as evidenced by the 7-day tests. The cylinders with 2 and 4 per cent then tested only 67 and 39 per cent, respectively, of normal. At 28 days and 1 year, the strengths of the linseed-oil cylinders more nearly approached normal, and at 1 year the cylinders with 4 per cent oil were less than 14 per cent weaker than the check cylinders. Absorption definitely decreased as the quantity of linseed oil was increased, and the 1-year tests of Medicine Lake cylinders indicated that resistance increased with quantity of linseed oil used.

Automobile oil, with Society of Automotive Engineers viscosity classification of 30, when used in quantities of 1, 2, 4, and 8 per cent very markedly reduced absorption. However, the effect of this oil on compressive strengths was not pronounced, except at 7 and 28 days for cylinders containing 8 per cent and 1 year for cylinders containing 4 and 8 per cent, which all averaged 19 per cent lower

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in strength than the check cylinders without oil. The effect on resistance to sulphates was hardly appreciable at one year, except on the cylinders with 8 per cent oil which made the poorest showing.

Kerosene used in quantities of 1, 2, 4, and 8 per cent appreciably reduced absorption by the cylinders and somewhat reduced 7-day strengths. In proportions under 8 per cent, kerosene had slight effect on 28-day strengths but apparently reduced the strength at one year. The effect of kerosene on resistance to sulphates was inappreciable at one year.

Water-gas tar, a thin liquid with 70 per cent soft pitch residue at 300° C., when added with the mixing water in proportions equivalent to 5 and 20 per cent of the weight of the cement, greatly reduced compressive strengths at 7 and 28 days. The resistance of cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate was below normal for those with 5 per cent of water gas tar, but very definitely above normal for those with 20 per cent.

RECAPITULATION OF RESULTS WITH ADMIXTURES

The 26 admixtures used did not, as a whole, increase the resistance of concrete to sulphate attack enough to justify their use for this purpose. A few, however, seemed to show definite possibilities, particularly in conjunction with the relatively high curing temperatures of 100° and 155° F., which are comparable to those used at many plants making draintile and other concrete products. Tests of cylinders from a number of the admixture series have not been made for exposure periods beyond one year, but the results of the 1-year tests do not indicate that any of those admixtures will show definitely beneficial results at five years. The admixtures which the 5-year tests indicate as holding most promise are the following:

Ironite, 20 per cent, used in cylinders cured at 155° and 100° F., which tested, respectively, 94 and 87 per cent of normal strength after five years in Medicine Lake.

Cal, 4 and 8 per cent, used in cylinders cured at 155° F., which tested, respectively, 82 and 93 per cent of normal strength after five years in Medicine Lake.

Calcium chloride, 4 and 8 per cent, used in cylinders cured at 155° F., which tested, respectively, 84 and 82 per cent of normal strength after five years in Medicine Lake.

Blast-furnace slag, 40 per cent, used in cylinders cured at 155° F., which made an excellent showing in 1 per cent solutions of sodium sulphate in the laboratory and after five years in Medicine Lake showed 48 per cent of normal strength.

Trass additions of 33 and 66 per cent, which definitely increased the resistance of cylinders stored in Medicine Lake, although no series averaged more than 42 per cent of normal strength. Substituted for 25 and 40 per cent of the cement, trass gave about the same results as the somewhat larger quantities added to the batch.

Volcanic ash, 20 per cent, which gave excellent results in water-cured cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate, but failed to develop increased resistance under the more severe exposure conditions of Medicine Lake except for the cylinders vapor-cured at 100° F., which tested 43 per cent of normal strength at five years.

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Moler, a diatomaceous silica used to replace 33⅓ per cent of the cement by mixing with the cement clinker before grinding, apparently caused an increase in resistance although, under the conditions tested, definite conclusions are not possible. (See special cement X, Table 22.)

SURFACE TREATMENTS

Treating the surface of concrete to protect it against sulphate action must be complete to be long effective. Even very slight disintegration destroys the bond between concrete and coating, and the action progresses at an increasing rate as the area of loosened coating becomes larger. Coatings that are more or less water-tight therefore rarely do more than somewhat retard early action. Comparatively few tests of this type are here reported, as experiments with only four products were conducted. The results of these tests are given in Table 33. The appearance of cylinders treated with two of these substances, after some years in Medicine Lake, is shown in Plate 9. The report by Lord (*31*) on experiments with surface-treated concrete cylinders in Medicine Lake is of interest in this connection.

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TABLE 33.—*Tests of 2 by 4 inch concrete cylinders given various surface treatments, cured in water and air and exposed to the action of sulphate water of Medicine Lake, S. Dak., as compared with similar cylinders stored in tap water*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1 : 3. Each test result, with a few exceptions is an average of five cylinders made on different days. Figures in parentheses, in compression test columns, indicates per cent of normal strength based on parallel tests of cylinders from the same batches, stored in tap water in the laboratory]

Series	Cement laboratory No.	Cement	Water ratio	Surface treatment or impregnation	Curing method			Absorption at 21 days	Average compression tests (pounds per square inch)						
									Tank specimens				Lake specimens		
					Time in moist closet	Time in water	Time in air		7 days	28 days	1 year	5 years	1 year	3 years	5 years
					Hours	*Days*	*Days*	*Per cent*							
374	74	½A and ½B1	0.62	Inertol, first coat at 22 days, second at 26 days.	24	20	35	6.7	2,930	4,870	5,570	6,200	5,390 (97)	3,310	5,320 (86)
[1] 375	74	do	.64	do	24	20	35	10.5	1,430	2,790	3,640	3,740	2,970 (82)	0	0
391	74	do	.62	None	24	20	35	6.3	3,130	4,890	6,060	6,430	2,480 (41)	0	0
549	129	do	.62	None. Dipped in boiling water ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,790	4,770	6,550	7,750	1,620 (25)	0	0
550	129	do	.62	Boiled linseed oil at 70° F., dipped ½ minute at 28 days.	24	20	35	5.8	3,540	4,960	6,040	6,520	5,520 (91)	5,220	4,210 (65)
551	129	do	.62	Boiled linseed oil at 70° F., dipped ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,730	5,260	5,520	6,970	5,730 (104)	5,560	2,930 (42)
552	129	do	.62	Boiled linseed oil at 225° F., dipped ½ minute at 28 days.	24	20	35	5.8	3,430	4,680	5,970	6,820	5,330 (89)	5,260	2,410 (35)
553	129	do	.62	Boiled linseed oil at 225° F., dipped ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,750	4,960	5,510	6,830	5,650 (103)	5,050	1,940 (28)
554	129	do	.62	None	24	20	35	6.3	3,570	4,760	5,980	6,820	3,530 (59)	0	0
934	245	do	.62	McEverlast special paving coating, 1 brush coat at 24 hours.	24	------	55	4.0	4,370	5,270	6,030	------	5,610 (93)	3,020	------
935	245	do	.62	McEverlast special paving coating, 1 brush coat at 21 days.	24	20	35	5.8	4,340	5,640	5,440	------	5,710 (105)	0	0
976	237	do	.62	None	24	20	35	6.0	3,700	4,590	5,750	------	4,650 (81)	0	0
977	237	do	.62	McEverlast penetration, 1 brush coat at 24 hours followed by 1 brush coat concrete cover coat at 48 hours.	24	------	55	2.7	2,890	4,180	5,660	------	4,710 (83)	4,780	------
978	237	do	.62	McEverlast penetration, 1 brush coat at 21 days followed by 1 brush coat concrete cover coat at 22 days.	24	20	35	2.1	3,670	4,650	5,740	------	5,550 (97)	3,120	------
979	237	do	.62	McEverlast paving special, 1 brush coat at 24 hours followed by 1 brush coat concrete cover coat at 48 hours.	24	------	55	4.5	3,200	4,410	5,620	------	4,920 (88)	3,770	------
980	237	do	.62	McEverlast paving special, 1 brush coat at 21 days followed by 1 brush coat concrete cover coat at 22 days.	24	20	35	2.0	3,410	4,450	5,780	------	5,250 (91)	3,450	------
[1] 293	19	do	.64	None	24	20	35	9.9	1,420	2,240	3,850	3,740	2,140 (56)	0	0
[1] 294	19	do	.64	Sulphur impregnated	24	20	35	9.9	1,350	2,210	3,130	2,610	1,500 (48)	0	0

[1] Standard Ottawa sand cylinders.

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The results of the study of surface treatments are very generally summarized as follows:

Inertol appreciably retarded sulphate action on concrete cylinders, but at the end of five years this coating afforded only slight protection.

Boiled linseed oil, both one coat and two coats, whether applied at room temperatures or heated to 225° F., appreciably retarded action on concrete cylinders up to four years and apparently afforded a slight measure of protection beyond about five years.

McEverlast afforded some protection up to two years and indicated a slight protection beyond about three years.

Sulphur impregnation afforded concrete no protection against disintegration in Medicine Lake.

CONCLUSIONS

Detailed conclusions on the effect of many factors on resistance of concrete to sulphate action are incorporated in various sections of this bulletin dealing with those factors.

The severity of action on concrete of pure solutions of either magnesium or sodium sulphate increases with the strength of solution, but at a diminishing rate for strengths greater than 1 per cent.

The destructive action of magnesium sulphate does not differ greatly from that of sodium sulphate in solutions of equal strength, although the latter averaged slightly more severe with most of the 35 Portland cements used in these tests.

The 28-day strength is a fair index of resistance for concrete of any given cement and given curing conditions, but may have no significance for comparing concretes made of cements from different mills or when the concretes are cured under widely different conditions.

Under identical exposure conditions, concrete made of a highly resistant Portland cement may last 10 times as long as that made of a cement of low resistance. Neither standard physical tests nor ordinary chemical analyses give any indication of the resistance of a cement to sulphate action. Qualities of the raw material associated with the geological formations from which it comes may be factors in the resistance of a cement.

Resistance of concrete is markedly increased by curing in water vapor at temperatures of 212° to 350° F., almost to the point of immunity to action for the most favorable temperatures and curing periods. Resistance is not increased, however, by raising the curing temperatures until 212° is reached, except in connection with the use of certain admixtures.

The admixtures Ironite, Cal, calcium chloride, blast-furnace slag, trass, moler, and possibly volcanic ash have appreciably retarded sulphate action on concrete cured at room temperatures. Results were outstanding, however, only as the relatively high curing temperatures of 100° and 155° F. were used in conjunction with Ironite, and 155° with Cal and calcium chloride. Under these conditions, cylinders had the highly satisfactory values of 82 to 94 per cent of normal strengths after five years in Medicine Lake, S. Dak.

Special cements other than alumina cements have not shown a degree of resistance that would justify preference over the more resistant of the Portland cements, except possibly an imported mason's cement containing 33⅓ per cent diatomaceous silica (moler) mixed with the cement clinker before grinding.

Each of the three alumina cements tested resisted sulphate action to a degree that approached the ideal, but displayed definite indica-

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tions of instability when used in concretes and mortars stored for long periods in tap water at room temperatures.

RECOMMENDATIONS AND SUGGESTIONS

Some of the following recommendations apply to all types of concrete to be exposed to sulphate attack, and some are applicable only to concrete pipe and other products similarly manufactured.

The resistance of a cement which is to be exposed to sulphate action should be tested in accordance with the routine suggested on page 43. Cements very low in resistance may then be rejected. Only cements that are above the average in resistance should be considered for use where sulphates are known to be present.

With any given cement and any predetermined conditions of curing, care should be observed in all particulars to obtain the highest practicable 28-day strength. That strength, although fallible for comparing different concretes, has much value as an index of the permeability and sulphate resistance of the products of the same cement and method of manufacture, particularly with rich mixes.

Concrete should be kept from intimate contact with sulphates until it has had opportunity to dry and harden in air for the longest time practicable. Depending on the particular cement used, air hardening may greatly increase resistance and, as a precautionary measure, should be continued for 30 days if possible, and 90 days or longer is desirable.

To develop the highest resistance in draintile, sewer pipe, and other products of concrete, they should be steam cured when 12 to 24 hours old at temperatures of 212° F. or higher for 48 hours or longer.

Alumina cement may be used advantageously for concrete structures subject to extremely severe conditions of sulphate exposure if the concrete will be continuously moist at temperatures generally below 60° F. and rarely exceeding 70° F. These moisture and temperature conditions are about the average for draintile after installation.

The following results of the experiments suggest methods of increasing the resistance of concrete to sulphate attack, but check tests are too limited to justify basing definite recommendations on them.

Very resistant concrete has been made by using curing temperatures of 100° and 155° F. in conjunction with additions of the commercial high-iron product Ironite, and equally good results have followed the use of curing temperatures of 155° in conjunction with additions of calcium chloride and of the calcium chloride product Cal. These results appear to hold some promise, as it is now common practice at many tile plants to use curing temperatures between 100° and 155°.

Concrete containing certain quantities of one of the admixtures Ironite, Cal, calcium chloride, trass, blast-furnace slag, and moler, after curing in water vapor at room temperatures, when exposed in Medicine Lake displayed resistance sufficiently increased to make the use of those materials seem justifiable where conditions of sulphate exposure are only moderately severe. These admixtures might have some merit in sea-water construction.

LITERATURE CITED

(1) Anonymous.
1921. Chemical analysis of cement as indications of behavior. Engin.-News Rec. 86:637–639, illus.

(2) Aberthaw Construction Company.
1920. Aberthaw tests of concrete in sea water. Rpt. 1920, 36 p., illus. Boston, Atlanta, [etc.].

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(3) ABRAMS, D. A.
1923. WATERPROOFING EFFECT ON CONCRETE STRENGTH. Concrete 22:216, illus.

(4) ———
1929. TESTS OF POWDERED ADMIXTURES IN CONCRETE. Amer. Soc. Testing Materials Proc. 29 (pt. 2): 618–653.

(5) AMERICAN SOCIETY FOR TESTING MATERIALS.
1930. STANDARD SPECIFICATIONS FOR DRAIN TILE (C4-24), 1930. A. S. T. M. Standards, 1930 (pt. 2): 249–264.

(6) ATWOOD, W. G., and JOHNSON, A. A.
1923. THE DISINTEGRATION OF CEMENT IN SEA WATER. Amer. Soc. Civ. Engin. Proc. 49:[1038]–1064.

(7) BATES, P. H.
1921. CEMENTING QUALITIES OF CALCIUM ALUMINATES. U. S. Dept. Com., Bur. Standards Technol. Paper 197, 27 p., illus.

(8) ——— PHILLIPS, A. J., and WIG, R. J.
1913. ACTION OF THE SALTS IN ALKALI WATER AND SEA WATER ON CEMENTS. U. S. Dept. Com., Bur. Standards Technol. Paper 12, 157 p., illus.

(9) BAUER, E. E.
1929. HIGH EARLY STRENGTH CONCRETE. Amer. Concrete Inst. Proc. 25:314–331, illus.

(10) BIED, J.
1909. EXPERIMENTS ON THE DECOMPOSITION OF MORTARS BY SULPHATE WATERS. Internatl. Assoc. Testing Materials Proc. Cong. 5, Paper 11–1, 10 p.

(11) ———
1922. ALUMINOUS CEMENT. Sci. Cong. Assoc. Engin. Liege School Sec. Civ. Engin. Rev. Universelle des Mines.

(12) BLOUNT, B.
1920. CEMENT. 284 p. London.

(13) BOGUE, R. H.
1929. CALCULATION OF THE COMPOUNDS IN PORTLAND CEMENT. Indus. and Engin. Chem. Analytic. Ed. 1:192–197, illus.

(14) BURKE, E., and PINCKNEY, R. M.
1910. THE DESTRUCTION OF HYDRAULIC CEMENTS BY THE ACTION OF ALKALI SALTS. Mont. Agr. Expt. Sta. Bul. 81, p. [49]–131, illus.

(15) BURKE, G. W.
1925. THE CHEMICAL ACTION OF ALKALI ON HYDRAULIC CEMENTS. Iowa Engin. Expt. Sta. Bul. 74, 54 p., illus.

(16) CANDLOT, E.
1897. THE INFLUENCE OF SEA WATER ON MORTARS. Translated from German by Carter and Giesler. Engin. Rec. 36:557–558.

(17) CONWELL, E. L.
1919. QUICK HARDENING CEMENTS. (Discussion.) Amer. Soc. Testing Materials Proc. 19:442.

(18) COWPER, A. D.
1927. LIME AND LIME MORTARS. [Gt. Brit.] Dept. Sci. and Indus. Research Bldg. Research Bd. Spec. Rpt. 9, 81 p.

(19) ——— and BRADY, F. L.
1927. POZZOLANAS. [Gt. Brit.] Dept. Sci. and Indus. Research, Bldg. Research Bd. Bul. 2, 10 p.

(20) ECKEL, E. C.
1921. QUICK HARDENING CEMENT DEVELOPED BY THE FRENCH . . . Engin. News-Rec. 87:566–567.

(21) ———
1922. CEMENTS, LIMES, AND PLASTERS; THEIR MATERIALS, MANUFACTURE, AND PROPERTIES. Ed. 2, rev. and partly rewritten, 655 p., illus. New York.

(22) FERET, R.
1890. EFFECT OF SEA WATER ON CONCRETE. Ann. Ponts et Chaussees 1:375.

(23) ———
1912. EFFECT OF SEA WATER UPON CONCRETE AND MORTAR. *In* Taylor, F. W., and Thompson, S. E., A Treatise on Concrete, Plain and Reinforced; Materials, Construction and Design of Concrete and Reinforced Concrete. Ed. 2, ch. 16, p. 309–318. New York.

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(24) [Great Britain] Department of Scientific and Industrial Research, Building Research Board.
1926. report of the director of building research for the period ended 31st december, 1926. [Gt. Brit.] Dept. Sci. and Indus. Research, Bldg. Research Bd. Rpt., 1926: 8–106, illus.

(25) Headden, W. P.
1908. destruction of concrete by alkali. Colo. Agr. Expt. Sta. Bul. 132, 8 p.

(26) Hughes, C. A., and Levens, A. S.
1930. strength and shrinkage of mortars made with blends of portland cement and puzzuolanic materials. Amer. Concrete Inst. Proc. 27: 317–337, illus.

(27) Jewett, J. Y.
1908. cement and concrete work of united states reclamation service with notes on disintegration of concrete by alkali water. Amer. Soc. Testing Materials Proc. 8: 480–493.

(28) King, F. V., Ervin, G., and Evans, O. L.
1925. a bibliography relating to soil alkalies. U. S. Dept. Agr. Bul. 1314, 40 p.

(29) Lagaard, M. B.
1927. integral waterproofing compounds for concrete. Minn. Engin. Expt. Sta. Bul. 6, 25 p., illus.

(30) Le Chatelier, H.
1900. search for materials capable of resisting sea water. Ann. Mines ser. 8, v. 2, pt. 2. Cong. Internatl. des Materiaux de Const. 2. Paris.

(31) Lord, E. C. E.
1931. effect of water-gas tar on the strength and alkali resistance of concrete. U. S. Dept. Agr. Public Roads 12: 109–116, illus.

(32) Michaelis, W.
1891–92. behavior of portland cement in sea water. Inst. Civ. Engin. [England] Minutes Proc. 107: 370–376.

(33) Miller, D. G.
1924. curing conditions of concrete drain tile a factor of resistance to sulfate waters. Concrete 24: 235–238, illus.

(34) ———
1926. four important factors in the manufacture of concrete pipe for alkali soils. Amer. Soc. Agr. Engin. Trans. 20 : 180–188.

(35) ———
1927. review of work of cooperative drain tile laboratory with recommendations. 14 p., (Published under direction of . . . [Minn.] Dept. Drainage and Waters).

(36) ———
1928. resistance of portland-cement concrete to the action of sulphate waters as influenced by the cement. Amer. Soc. Testing Materials. Proc. 28 (pt. 2): 448–471, illus.

(37) ———
1930. strength and resistance to sulphate waters of concrete cured in water vapor at temperatures between 100° and 350° f. Amer. Soc. Testing Materials Proc. 30 (pt. 2): 636–653, illus.

(38) ——— and Manson, P. W.
1931. the action of sulphate water on concrete. recent tests of specimens immersed in medicine lake, s. dak. U. S. Dept. Agr. Public Roads 12: 64–85, illus.

(39) Page, L. W.
1912. oil-mixed portland cement concrete. U. S. Dept. Agr., Off. Pub. Roads Bul. 46, 28 p., illus.

(40) Pagon, W. W.
1915–16. report on the destructive action of sea water on concrete and methods of guarding against it. Baltimore Engin. Club Jour. 5, nos. 2, 3, 4, 6, 7, 8, 9.

(41) Pearson, J. C., and Brickett, E. M.
1932. studies of high-pressure steam curing. Amer. Concrete Inst. Proc. 28: 537–550, illus.

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(42) PEPPEL, S. V.
1905. MANUFACTURE OF ARTIFICIAL SANDSTONE OR SAND LIME BRICK. Ohio Geol. Survey Econ. Geol. 9, Bul. 5, 79 p.

(43) POULSEN, A.
1923. CONCRETE AND REINFORCED CONCRETE. Thirteenth Internatl. Cong. Navigation, London.

(44) SMEATON, J.
1791. NARRATIVE OF THE BUILDING OF THE EDDYSTONE LIGHTHOUSE, 1791.

(45) SPACKMAN, H. S.
1910. THE ALUMINATES: THEIR PROPERTIES AND POSSIBILITIES IN CEMENT MANUFACTURE. Amer. Soc. Testing Materials Proc. 10:315–327.

(46) STEIK, K.
1917. EFFECT OF ALKALI UPON PORTLAND CEMENT. Wyo. Agr. Expt. Sta. Bul. 113, p. [71]–122, illus.

(47) TANNATT, E. T., and BURKE, E.
1908. EFFECT OF ALKALI UPON PORTLAND CEMENT. Mont. Agr. Expt. Sta. Bul. 69, p. [93]–120, illus.

(48) THORVALDSON, T., and VIGFUSSON, V. A.
1928. THE EFFECT OF STEAM TREATMENT OF PORTLAND CEMENT MORTARS ON THEIR RESISTANCE TO SULPHATE ACTION. Engin. Jour. [Canada] 11:174–179, illus.

(49) ——— WOLOCHOW, D., and VIGFUSSON, V. A.
1932. STUDIES ON THE ACTION OF SULPHATES ON PORTLAND CEMENT. PART 4. ACTION OF SULPHATE SOLUTIONS ON MORTAR PREPARED FROM SOME BINARY AND TERNARY COMPOUNDS OF LIME, SILICA, ALUMINA, AND IRON. Canad. Jour. Research 6:485–517.

(50) VICAT, L. J.
1818. BRARD'S SODIUM SULPHATE TEST. English translation by J. T. Smith, 1835, p. 216–217.

(51) ———
1857. RECHERCHES SUR LES CAUSES PHYSIQUES DE LA DESTRUCTION DES COMPOSES HYDRAULIQUES PAR L'EAU DE MER. Bul. Soc. Encouragement Indus. Natl.

(52) WHITE, A. H., and BATEMAN, J. H.
1926. SOAPS AS INTEGRAL WATERPROOFING FOR CONCRETE. Amer. Concrete Inst. Proc. 22:535–559, illus.

(53) WIG, R. J.
1912. EFFECT OF HIGH-PRESSURE STEAM ON THE CRUSHING STRENGTH OF PORTLAND CEMENT MORTAR AND CONCRETE. U. S. Dept. Com., Bur. Standards Technol. Paper 5, 25 p., illus.

(54) ——— and WILLIAMS, G. M.
1915. INVESTIGATIONS OF THE DURABILITY OF CEMENT DRAIN TILE IN ALKALI SOILS. U. S. Dept. Com., Bur. Standards Technol. Paper 44, 56 p., illus.

(55) ——— WILLIAMS, G. M., and FINN, A. N.
1917. DURABILITY OF CEMENT DRAINTILE AND CONCRETE IN ALKALI SOILS. (CONTAINING RESULTS OF THIRD YEAR'S TESTS). U. S. Dept. Com., Bur. Standards Technol. Paper 95, 94 p., illus.

(56) WILEY, C. C.
1929. EFFECT OF TEMPERATURE ON THE STRENGTH OF CONCRETE. Engin. News-Rec. 102:179–181, illus.

(57) WILLARD, E. V., and MILLER, D. G.
1921. REPORT OF CONCRETE-ALKALI INVESTIGATIONS IN MINNESOTA, 1919–1920. Minn. Dept. Drainage and Waters Rpt. 1921, 74 p., illus.

(58) WILLIAMS, G. M.
1922. DURABILITY OF CEMENT DRAIN TILE, AND CONCRETE IN ALKALI SOILS: THIRD PROGRESS REPORT (1919–20). U. S. Dept. Com., Bur. Standards Technol. Paper 214, p. 463–494, illus.

(59) ——— and FURLONG, I.
1926. DURABILITY OF CEMENT DRAIN TILE AND CONCRETE IN ALKALI SOILS: FOURTH PROGRESS REPORT (1923). U. S. Dept. Com., Bur. Standards Technol. Paper 307, p. 191–240, illus.

(60) WOODWORTH, P. M.
1930. SOME TESTS OF CONCRETE MASONRY UNITS CURED WITH HIGH PRESSURE STEAM. Amer. Concrete Inst. Proc. 26:504–512.

(61) YOUNG, R. N.
1920. EFFECT OF CAL AS AN ACCELERATOR OF THE HARDENING OF PORTLAND CEMENT MIXTURES. U. S. Dept. Com., Bur. Standards Technol. Paper 174, 24 p., illus.

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FARMERS' RESPONSE TO PRICE IN HOG PRODUCTION AND MARKETING

BY

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Bureau of Agricultural Economics

United States Department of Agriculture, Washington, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

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By ORIS V. WELLS,[1] *Assistant Agricultural Economist, Division of Farm Management and Costs, Bureau of Agricultural Economics*

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INTRODUCTION

The mass reaction of hog production to price is the final summation of the individual responses of the 3,500,000 hog producers in the United States. This mass response is an important factor in determining the central market price. But to understand and to control this mass reaction, the individual responses must be considered.

In the analyses that have been made in the past, attention has been centered upon the problem of the mass response, and little or no effort has been made to obtain either a general or a statistical description of the individual responses that are combined in the mass response.

In 1924 Wright (*8*) [2] advanced the general proposition that corn supplies, corn prices, hog prices, and hog supplies formed a compact interrelated system in which hog production was largely dependent upon variation in the corn-and-hog price system. This general analysis was supported, in turn, by a technical-correlation analysis of the available United States corn and hog data for the period from 1870 through 1915.

In 1926 Haas and Ezekiel (*3*) developed a qualitative explanation of the variation in hog supplies as a result of changes in the corn-hog

[1] The project from which this bulletin has developed was planned by F. F. Elliott, formerly senior agricultural economist, Division of Farm Management and Costs. The author is indebted to F. F. Elliott, C. L. Holmes, principal agricultural economist in charge, Division of Farm Management and Costs, C. L. Harlan, principal agricultural statistician, Division of Crop and Livestock Estimates, and G. B. Thorne, agricultural economist, Division of Statistical and Historical Research for helpful advice and criticism. Credit is also due Della Merrick for help in the preparation of the statistical material.

[2] Italic numbers in parentheses refer to Literature Cited, p. 57

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differential. Elliott (*2*) analyzed in 1927 the relation between the September-through-April market receipts of hogs at Chicago from 1898 through 1915 and the corn-hog ratio, and decided that the variation in the corn-hog ratio was the chief determinant of changes in subsequent hog supplies from year to year.

In 1928 Russell (*4*) explained the year-to-year changes in hog marketings by previous changes in the corn-hog ratio, and the seasonal distribution of marketings through the hog-marketing year by changes in the preceding summer corn-hog ratio and the size of the current corn crop.

These analyses have developed an excellent general explanation of the farmer's response to price in hog production, but they have been based chiefly upon pre-war data and have been almost wholly concerned with the single question: What causes the total number of hogs marketed in the United States to change from year to year?

To obtain a more complete explanation of the farmers' response to price in hog production and marketing and to develop a simple statistical analysis of the available postwar data which may be easily reworked or extended, the analysis presented in this bulletin was made.

To begin with, a general explanation was developed of the changes that hog producers may be expected to make in their production and marketing policies in response to changes in the corn-and-hog price system. This explanation was then checked by a series of statistical analyses which measured the effect of changes in hog supplies upon concurrent hog prices and of changes in the corn-and-hog price system upon subsequent hog supplies and marketing practices in the period from 1919 into 1931. Next, a large number of the innumerable individual responses which combine to form the single mass response were studied to obtain information as to whether certain classes of hog producers are more responsive or more sensative to price changes than are certain other classes. Then, upon the basis of the general explanation and the statistical analyses of both the mass and the individual response data, consideration was given to the extent to which, and the manner in which, hog producers may be expected to adjust their production and marketing policies to meet the demand situation from season to season.

HOG SUPPLIES AND HOG PRICES

WHY HOG SUPPLIES FLUCTUATE

The general reason why farmers increase or decrease their hog production and subsequent marketings from season to season is simple. As they wish to obtain a maximum income from their farms, they tend to increase their hog production when the feed supply is plentiful and hog prices are high and to decrease production when the situation is reversed.

But this general principle is not an exact explanation of why farmers increase or decrease their hog production from season to season and their rate of marketing from time to time during the season. A more exact explanation is needed. Such an explanation should consider not only why hog production changes from year to year but also to what price factor the typical hog producer is most responsive and to what extent his response is conditioned by the time period involved.

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There are two reasons why hog production changes so much from year to year. The first is that, since hog production is a rather rapid process in comparison with beef or dairy production, farmers can increase or decrease the number of pigs born and fattened and the weight at which they are marketed within a comparatively short time. The second reason is that hog production is largely dependent upon a single feed crop. Although some mill feed, some tankage, some skim milk, and some wheat and pasturage are used, corn is the main hog feed. When the corn supply is short, as in 1924, some livestock enterprise must be cut, and when the supply is large, as in 1920 and 1921, an expansion in some livestock enterprise is to be expected. The elastic hog enterprise is the natural place for this expansion and contraction.

With respect to price, the typical hog producer is naturally as much interested in the relative profit he can make as in the actual price he can get for his product. This indicates that the price factor to which the producer might be expected to respond most readily is the price of hogs relative to some alternative product. But the typical hog producer may have a number of alternative enterprises open to him, and different producers may have different alternatives to consider, so an actual measure of an alternative or a relative price to which all producers respond can not be obtained.

The price measure desired is the best average measure of hog prices relative to the many alternatives that are open to American hog producers. Since corn is the chief hog feed, since the bulk of the United States hog supply is produced in the Corn Belt, since the most common alternatives open to the hog producer are the livestock enterprises—sheep, beef cattle, and dairying—which are also based in part upon corn, and since the important corn market is the farm market, the corn-hog ratio is seemingly this best average measure.

As indicated in Figure 1, in which the Chicago-price corn-hog ratio [3] is compared with the 12-month moving average of the number of hogs slaughtered under Federal inspection, there is a good agreement between the major changes in the corn-hog ratio and the subsequent changes in the short-time trend of hog marketing as measured by the slaughter data. For example, from 1920 until the first part of 1922, hog marketings were about average, but two 3,000,000,000-bushel corn crops caused corn prices to decline, and as a result, the corn-hog ratio—which is the price of hogs divided by the price of corn—was raised well above the long-time average. This high corn-hog ratio, in turn, encouraged hog production and caused the record hog marketings of 1922–23 and 1923–24.

In most cases the response is apparently made to the corn-hog ratio current at the time the farmer makes and executes his breeding plans. The ratio during the last quarter of the calendar year is the most influential factor in determining the size of the coming spring pig crop, and the ratio through the first half of the year is important in determining the size of the fall crop. Actually, however, since the farmers' marketing plans are influenced to some extent by the ratio through every month of the year and since the ratios are so highly correlated

[3] The term "corn-hog ratio" as used in this bulletin refers to the number of bushels of corn required to buy 100 pounds of live hogs and is computed by dividing the per hundredweight hog price by the per-bushel corn price. The corn-hog ratio charted in Figure 1 is based upon the average price at Chicago of hogs and No. 3 yellow corn. This ratio is different from the United States average farm-price ratio regularly published in Crops and Markets.

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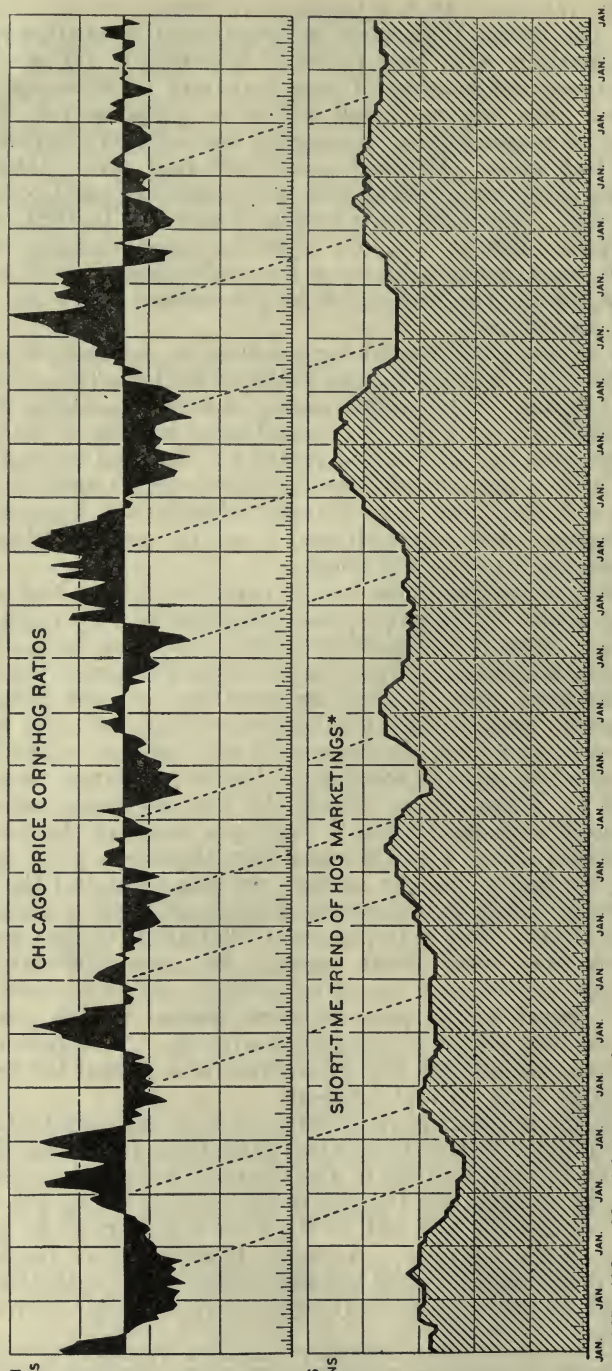

FIGURE 1.—CORN-HOG RATIOS AND HOG MARKETINGS, 1907–1931

When hog prices are high relative to corn prices, as in 1921–22, hog production as measured by subsequent marketings is increased; when the ratio is reversed, as in 1923–24, production is decreased.

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with each other from month to month, the hog-year ratio is often as accurate a price measure as is the 3-month breeding-season ratio.[4]

Although the corn-hog ratio is the price factor to which the typical farmer is most responsive, other price and nonprice influences are often important. If an individual farmer's response is being considered, there are many price influences to which he may respond and an innumerable number of nonprice influences which may condition his price response.

If the collective national response is being considered, the three general price influences that may be expected to modify the farmers' initial corn-hog ratio response are hog prices, the general level of beef-cattle and dairy-product prices, and commercial feed prices. The most important nonprice influences to be considered are spring weather and disease. Mild weather at farrowing time naturally means that a larger percentage of pigs is saved than normal; severe weather has the opposite effect. Although usually inoperative, the second nonprice factor—disease—may become especially important as a reduction factor.

The farmers' response to price is also conditioned by the time period within which the reaction or price response is made. With respect to time, there are three clearly defined price responses that the hog producer may make. These are:

(1) The short-time marketing response. This response, which is made to actual hog prices, and which is usually completed in much less than 15 days, is essentially a marketing response. When the price through any given day is high relative to the prevailing weekly or seasonal level, the expectation is that the marketings of hogs already finished will be speeded up in the near future; when prices temporarily drop below the prevailing level, decreased marketings are to be expected.

(2) The seasonal response. This response, which is a composite reaction to actual prices, to the corn-hog ratio, and to the corn supply situation, influences both the weight at which hogs are marketed and the seasonal distribution of marketings through the hog-marketing year. A large corn crop and a high corn-hog ratio may be expected to increase weights and to retard the rate of marketing through the late fall and winter. A small crop and a low ratio will usually decrease weights and accelerate the rate of marketing through the winter.

(3) The hog-year production response. This response, which is made to the corn-hog ratio, is especially important because it influences the number of sows that farrow from season to season. When the corn-hog ratio is high at breeding time, increased marketings may be expected 12 to 18 months later, and when the ratio is low, decreased marketings may be expected.

WHY HOG PRICES FLUCTUATE

To determine and measure the effect of the hog producers' response to the current price situation upon subsequent hog prices, concurrent hog-supply and hog-price data may be related to each other. The first step is to decide upon the statistical data to be used.

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[4] The hog year, as distinguished from the calendar year, is the natural 12-month marketing period for hogs which begins when the spring-farrowed pigs begin to move to market in the fall and extends through the following summer.

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Actually, neither the available market-receipts data nor the federally inspected slaughter reports constitute an accurate measure of total hog slaughter. The market-receipts data are to be questioned, in part because hogs bought in one market and reshipped to a second market or sent to a farm feed lot are counted twice, and in part because these data do not always include direct-to-the-packer shipments.

Because of the marked increase, since 1920, in the direct buying of hogs by the large central packing houses and by the smaller interior packing plants, the inspected slaughter of hogs has been larger than the recorded market receipts since the 1925–26 hog year.

As the data regarding federally inspected slaughter are derived from the last step in the hog-production process and as all packing plants engaged in interstate commerce have been required to operate under the Federal-inspection system since 1906, these data may be con-

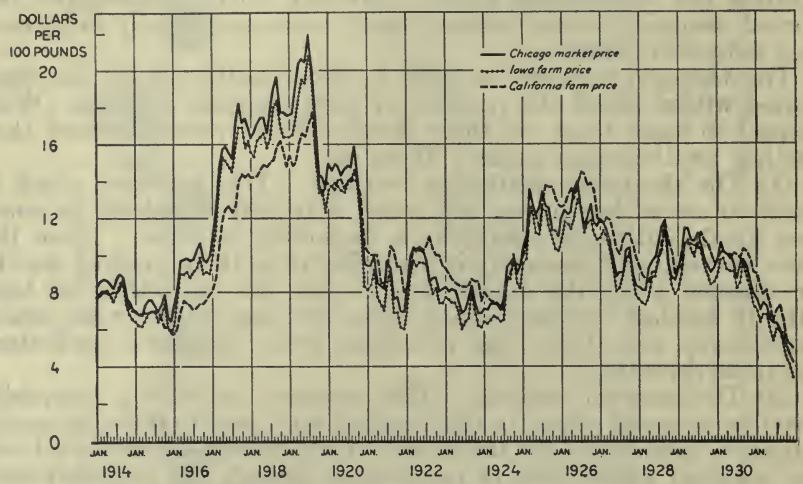

FIGURE 2.—CENTRAL-MARKET AND FARM HOG PRICES, 1914–1931

Farm and central-market hog prices tend to move up and down together. When the Chicago price is high, the price received by the producer at his local market in Iowa or in California is high, and when the Chicago price is low, the farm price is low.

sidered as the most accurate available measure of annual hog production. Even though inspected slaughter, or production of pork under Federal inspection, is not an exact measure of total production, an approximate estimate of the year-to-year changes in the unknown total can be obtained through a consideration of the relative year-to-year changes in the available data.

Selection of the representative price to be used is also a problem in sampling. But since modern communication and transportation connect the farm and central hog markets in an interrelated and flexible single marketing system, the average price paid for hogs by packers in the Chicago market, the average farm price in Iowa, and the farm price in an isolated and relatively unimportant hog-producing State like California, are usually on the same relative level. (Fig. 2.) The actual differences between the central-market and the farm prices are to be expected and are mainly due to freight and marketing charges and to the local supply and demand situation.

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Since hog prices are more nearly determined in the large central markets than in the small and scattered farm markets, and since the Chicago prices are more readily available than are the closely related farm prices, the average price of hogs to packers at Chicago may well be used as a representative price to match against the inspected-slaughter data.

In Figure 3, the hog-year production of pork (and lard) under Federal inspection in billions of pounds is represented on the horizontal scale and the weighted-average Chicago price in dollars per live hundredweight on the vertical scale. The data regarding actual price and slaughter are represented by the heavy dots on the chart which are labeled with their corresponding dates—for example, "1928" is used to mean the hog-marketing year beginning in October, 1928.

The average relationship between hog supplies and prices, for the 12-year period, is represented by the heavy diagonal line. On an average, an increase or decrease of 200,000,000 pounds of dressed pork was associated with an inverse decrease or increase of $0.35 in

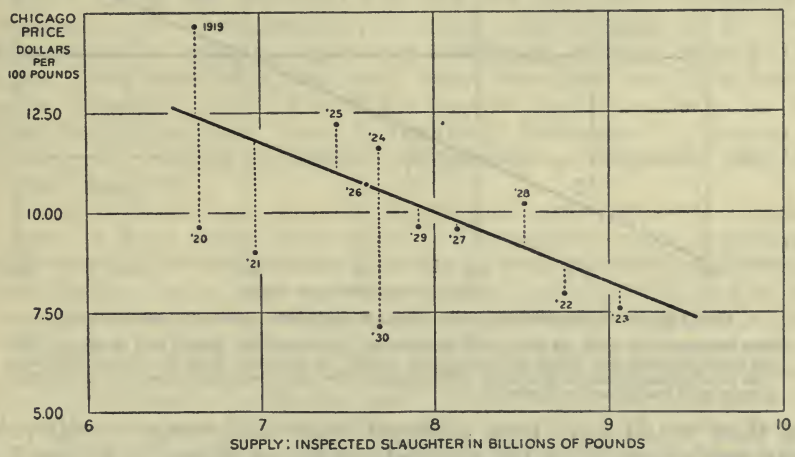

FIGURE 3.—HOG SUPPLIES AND HOG PRICES, 1919–1930

As hog supplies increase or decrease, hog prices tend to move in the opposite direction. From 1919 through 1930, each 200,000,000-pound change in the supply measure was accompanied by an average change of 35 cents in the price measure, as indicated by the diagonal line. (See fig. 4.)

price per live hundredweight at Chicago. This average relationship, although important, does not explain all the variation in hog prices through the period, for if the explanation were complete the actual data would all lie exactly on the diagonal supply-price line.[5]

Prices represent an interaction of the supply and demand factors in the market. Since the effect of the supply factor has been measured, the next step is to relate the still-unexplained portion of the prices charted in Figure 3 to an index or measure of the demand factor. In Figure 4, a measure of this demand relationship is shown. Since slaughtered hogs must be sold or used within a short time as meat, and since the inspected-slaughter data used in Figure 3 exclude farm

[5] The method of graphic analysis used in this problem is a simple approach to technical multiple correlation as developed by Bean (*1*). If the correlation is high and the number of cases to be considered is small, this simpler method can be used to determine net regression or average-relationship lines in a much shorter time than that required to make a technical correlation computation. For a more extended discussion of this method see Evaluation of Analytic Method Used, p. 30.

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slaughter, the Federal Reserve Board index of industrial pay rolls should give an approximate measure of the general demand level.

In Figure 4, then, the unexplained variation in hog prices, as measured by the light broken vertical lines which connect the actual-price data with the supply price line in Figure 3, has been plotted against the pay-rolls index and the heavy diagonal line of average relationship has been drawn.[6] This demand factor, as indicated by the chart, is an important price determinant in the hog market. On an average, an increase or decrease of 2 points in the pay-rolls index was associated with a corresponding change of $0.25 per live hundredweight in the Chicago hog price.

But the addition of the industrial pay-rolls factor does not give a perfect explanation of the prices under consideration. For example, as shown in Figure 3, the actual price of hogs in 1920, when the general price level moved sharply downward and industrial depression was generally prevalent, was $9.60 per live hundredweight or $2.90

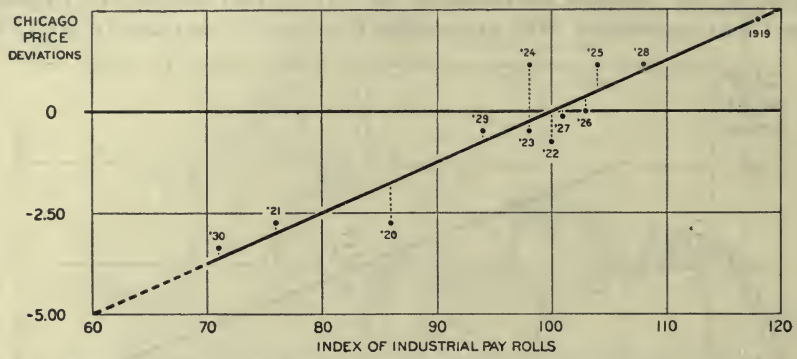

FIGURE 4.—INDUSTRIAL PAY ROLLS AND HOG PRICES, 1919–1930

When industrial pay rolls are above 100, or average, hog prices are higher and when pay rolls are below average, hog prices are lower than would be expected from the supply situation. The price measure used in this chart is the difference between the actual price and the diagonal supply-price line shown in Figure 3.

less than would have been expected from the average supply-price relationship; but when the pay-rolls factor, as shown in Figure 4, is considered, $1.70 of this difference is accounted for, so the actual price was $1.20 lower than would have been expected from the multiple relationship. Again, the actual price in 1925 was $1.40 more than the expected supply price and $0.80 higher than the expected supply-and-demand price.

These unexplained differences between the actual hog prices and those estimated or reconstructed from the average supply-and-demand measures indicate that there are still certain unconsidered factors that are important in the hog market. To obtain a more accurate analysis, the general price level, the population growth, the export or foreign demand, the storage supplies of pork, the corn situation, and the supplies of certain substitute commodities such as beef and lamb, are some additional factors to be considered. This simple statistical analysis, however, has been developed not as a price forecasting device but as an approximate measure of the importance of supply as a price-determining factor.

[6] A portion of the line of average relationship in Figure 4 has been drawn as a broken line. This device is used here, and will be used thoroughout this bulletin, to indicate that the broken portion of the line is statistically less significant or more questionable than the solid portion

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Through the 12-year period analyzed, the supply factor has been almost as important as the demand factor. But the changes in market supplies, which are partly responsible for the changes in market price, originate not in the market but on the farm. As farmers increase or decrease their hog-breeding operations and, in time, the volume of their marketings, they are themselves responsible in part for the lowered or increased prices they receive.

RESPONSE OF HOG PRODUCTION TO PRICE

WHY UNITED STATES SUPPLIES CHANGE

To begin the quantitative analysis of the response of hog production to price, an analysis of the year-to-year changes in the commercial hog production of the whole country may first be considered. To measure this production, the data of inspected slaughter have been used; and to obtain the best measure of the year-to-year change in slaughter or production, the slaughter for each hog year has been expressed as a percentage change or difference from the slaughter of the preceding year.

Since corn is the important hog feed and since both corn and hog production are concentrated in the north-central region, or the Corn Belt, monthly corn-hog ratios were calculated for each State in this region from farm-price data, and these were then combined into a single weighted ratio. The State weights used in calculating the Corn Belt ratio were: Iowa 3, Illinois 2, Nebraska 1.5, Kansas 1, Missouri 1, Indiana 1, Ohio 1, Minnesota 1, Wisconsin 0.5, and South Dakota 0.5.

These 10 States were selected because the great bulk of the market supply of hogs comes from them.[7] The weights were determined with reference to the average quantity of corn produced within each State during the 10-year period from 1919 through 1928, and to the average number of hogs marketed from each State during that period.

With the method of calculation decided upon for the measures of hog marketings and the corn-hog ratio, the next step was to decide upon the time period to be analyzed. Since the postwar data are more complete than the pre-war data, since the price and production of hogs through the war period may have been influenced by the United States Food Administration, and since the future actions of hog producers may be more in accord with their actions of the last 12 years than with those of the pre-war period, the period from 1919–20 through 1930–31 was selected.

WHY INSPECTED SLAUGHTER CHANGES

A simple graphic analysis of the relation between the percentage change in the (October through September) hog-year slaughter from one year to the next and the corn-hog ratio is presented in Figure 5.

In Figure 5, A, the percentage change in the inspected hog-year slaughter from year to year is related to the corn-hog ratio of the first preceding hog year. The average relationship is indicated by the heavy diagonal line. Although this relationship gives a partial explanation of the year-to-year changes, the residual or unexplained variation is large, as is indicated by the light dotted lines drawn

[7] For convenience, the term "Corn Belt" is used in this bulletin to refer to the 10 States listed above even though an exact geographic definition of the term would exclude a small portion of the area included in this general definition.

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vertically between the observation points and the regression or relationship line. In B the residual variation from A has been related

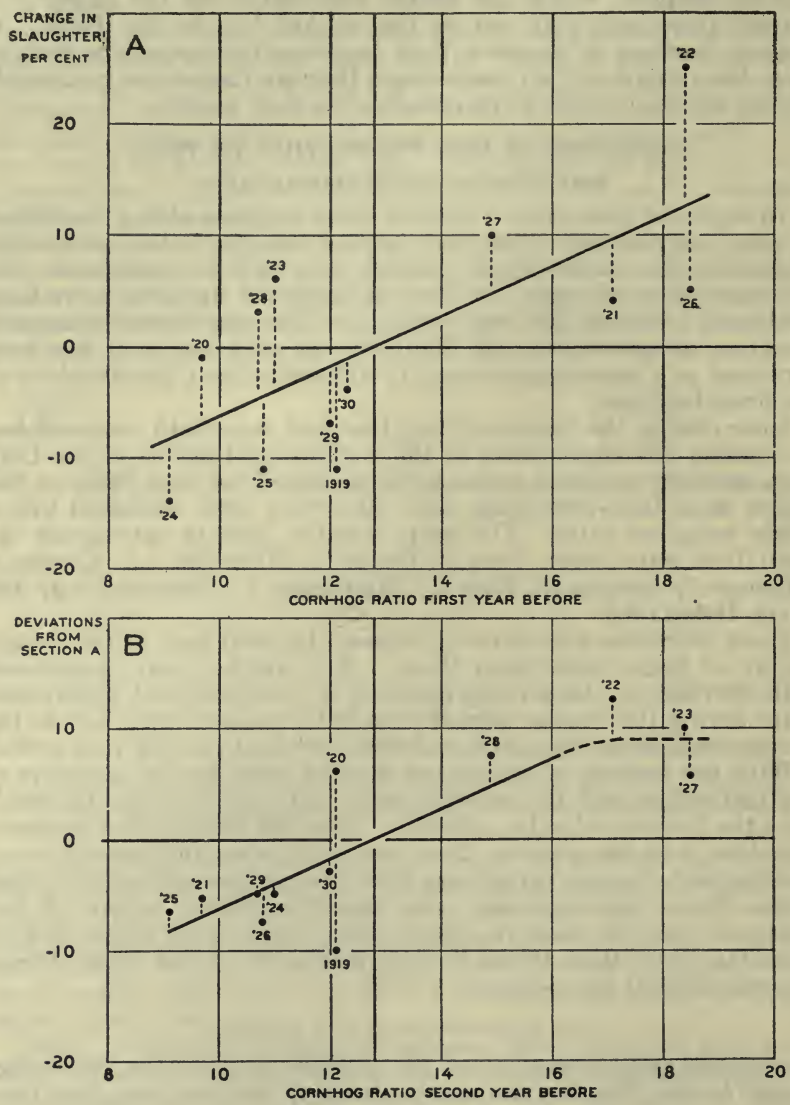

FIGURE 5.—RELATION BETWEEN THE CORN-BELT CORN-HOG RATIO AND THE YEAR-TO-YEAR CHANGES IN TOTAL FEDERALLY INSPECTED HOG SLAUGHTER, 1919–1930

The relation between the variation in the price of hogs relative to the price of corn and the changes in inspected slaughter (A) one year and (B) two years later is close and well defined. The slaughter measure used in section B is the difference between the actual percentage change in slaughter and the diagonal ratio-slaughter line in section A. Each observation dot is labeled with the date of the October in which the hog year began.

to the corn-hog ratio of the second preceding hog year. The average relationship is indicated by the heavy diagonal curve.

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Although the multiple relationship between changes in slaughter and the two corn-hog ratios does not give a perfect measure or explanation of the actual changes, it does give a good explanation. The corn-hog ratio, for example, of 14.9 for the first preceding year indicated (according to the regression line in Figure 5, A) an increase of 4.5 per cent in the number of hogs slaughtered under Federal inspection during the hog-year which began in 1927 over the number slaughtered during the hog-year which began in 1926, and the corn-hog ratio of 18.5 for the second preceding year indicated (according to the regression curve in B) an increase of 9 per cent. In comparison with an actual increase of 10 per cent, the net estimated or reconstructed increase was 13.5 per cent. This is shown in Figure 6, where the actual changes, represented by the solid bars, are directly

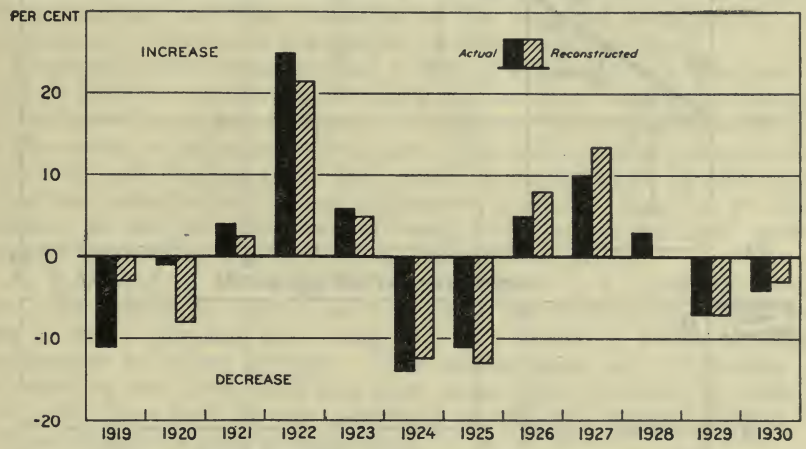

FIGURE 6.—ACTUAL AND RECONSTRUCTED CHANGES IN FEDERALLY INSPECTED HOG SLAUGHTER. 1919–1930

When the year-to-year changes in inspected slaughter are reconstructed from the analysis shown in Figure 5 and plotted in comparison with the actual changes, the close relation between the two is apparent.

compared with the reconstructed changes, represented by the shaded bars, for each year from 1919–20 through 1930–31.

WHY HOG NUMBERS CHANGE

The analysis just presented may be criticized because it is based upon inspected slaughter and sectional corn-hog ratio data instead of upon all-inclusive nation-wide data. Although the data necessary to secure an exact answer to such an objection are not available, an approximate answer may be obtained by relating the year-to-year changes in the January 1 number of swine on farms in the United States as estimated by the division of crop and livestock estimates to the average United States farm-price corn-hog ratio which is regularly published in Crops and Markets.

In Figure 7, A, the actual percentage change in hog numbers as of January 1 is related to the average corn-hog ratio in the first preceding calendar year. As indicated by the heavy diagonal curve of average relationship, decreasing numbers are associated with the lower ratios and increasing numbers with the higher.

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In Figure 7, B, the variation in the year-to-year changes in hog numbers which the first factor failed to explain has been related to the average corn-hog ratio for the second preceding calendar year. This

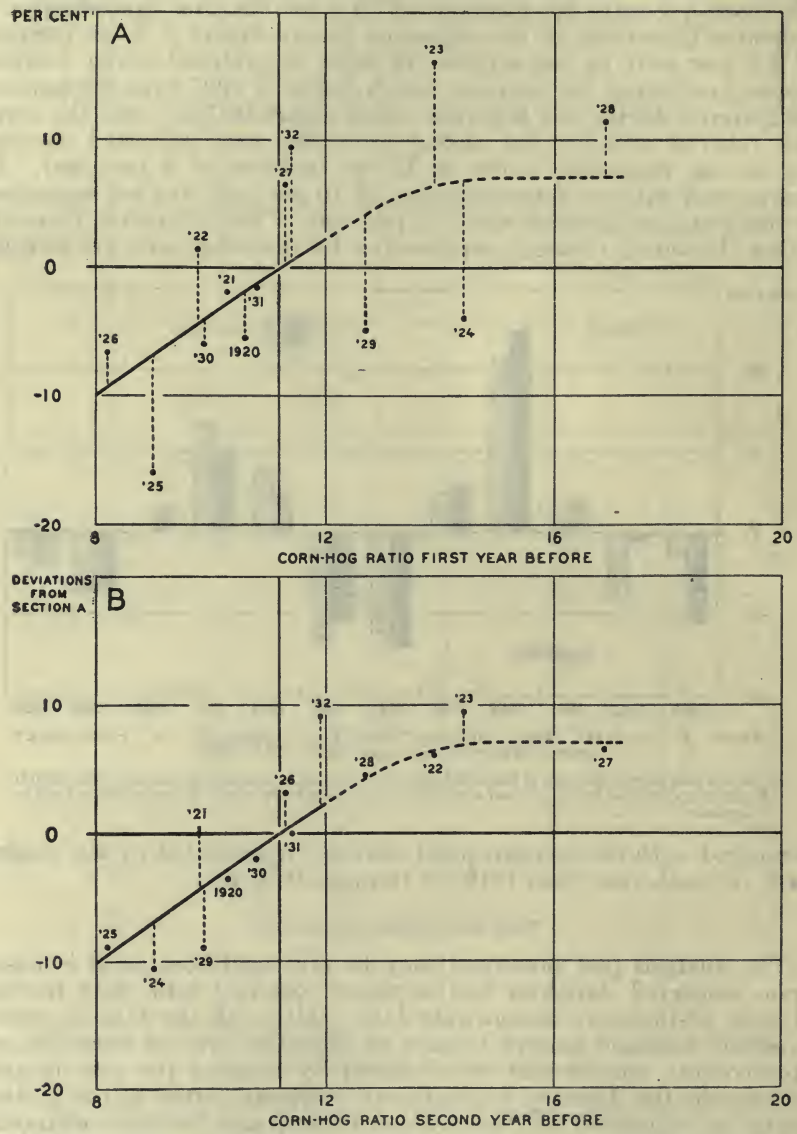

FIGURE 7.—RELATION BETWEEN THE CORN-HOG RATIO AND YEAR-TO-YEAR CHANGES IN UNITED STATES HOG NUMBERS ON JANUARY 1, 1920–1932

Year-to-year changes in hog numbers on January 1 are closely related to preceding changes in the corn-hog ratio (A) the first year and (B) the second year before. But, owing to the relatively large supply of small grain and the abnormal price situation in 1930–31, they were higher than was to have been expected on January 1, 1932.

second factor, in turn, gives a good explanation of the changes to which it has been related.

For January 1, 1932, however, the increase in hog numbers explained by, or reconstructed from, the two corn-hog ratios is con-

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siderably lower than the officially estimated increase. This difference is not a chance difference. Instead, it is the result of a special situation in 1930–31—of a relatively large supply of low-priced small grain in the Corn Belt, of the low price received for cotton in the South, and of the favorable effect of a moderate supply of hogs on the hog-price situation.

WHY MARKET WEIGHT CHANGES

The analysis presented in the section on the relation between hog production and the corn-hog ratio dealt with the hog-year supply or slaughter of hogs in terms of number. The actual supply, however, is the tonnage rather than the number marketed. Even though the variation in the average slaughter weight is small from year to year in comparison with the variation in the number slaughtered, the question of what causes the weight variation is important.

In general, the average market weight of hogs might be expected to vary in response to changes in the available corn supply, to changes in the corn-hog price ratio, and to changes in weight differentials in the central market price structure. Since the corn supply and the corn-hog ratio in the Corn Belt may be expected to be the most important weight-determining influences, a graphic analysis of their relation to the average dressed weight of hogs slaughtered under Federal inspection is presented in Figure 8, A and B.[8]

As indicated by the diagonal line in Figure 8, A, when the Corn Belt corn supply per hog is above average, the production of pork per hog is above average, and when the corn supply is below average, production is below average. This means that hog production is centered in the Corn Belt and that, since hogs are used to market corn, the Corn Belt farmer is inclined to feed the greater portion of his corn supply within a short time.

But, as indicated in Figure 8, B, the Corn Belt corn-hog ratio through the previous summer and the first part of the fall season is an important weight determinant. The influence of the ratio is a double influence. When the summer ratio is high, the hog producer will tend to increase the size of his fall pig crop, which will mean increased marketings the next summer and, since summer-marketed hogs average heavier than winter-marketed hogs, the average hog-year weight will be raised. Again, when the fall corn-hog ratio is high, the producer will tend to feed his spring-farrowed pigs to heavier weights, and when the ratio is low he will tend to save his corn.

As indicated by the unexplained variation in Figure 8, B, the corn supply and the corn-hog ratio influences do not give a sufficient explanation of the variation in weight. A third factor is necessary. This third factor, instead of being a price-differential factor as first expected, is obtained by calculating the percentage of the number of hogs in the United States on January 1 in the Corn Belt. Since 1919, hog production has tended to concentrate more and more in the western Corn Belt section where heavier-than-average hogs are produced, and, as a result, the average production of pork per hog slaughtered under Federal inspection has tended to increase. As is

[8] The weight measure used in this analysis is an average October-through-September hog-year production of dressed pork per hog slaughtered under Federal inspection. The corn-supply measure is based upon the annual corn production of the Corn Belt plus November 1 stocks of old corn and the number of hogs in the Corn Belt on the succeeding January 1. The corn-hog ratio is a 6-month, May-through-October, average Corn Belt corn-hog ratio.

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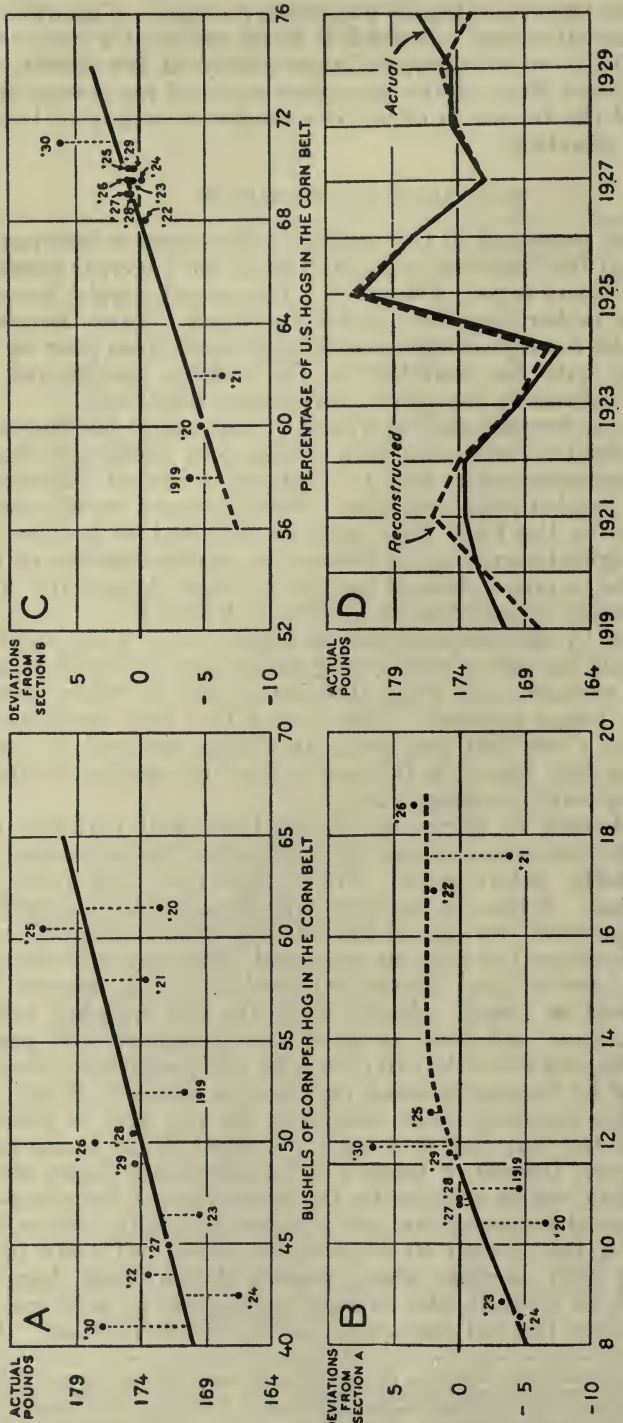

FIGURE 8.—ANALYSIS OF THE AVERAGE DRESSED WEIGHT OF HOGS SLAUGHTERED UNDER FEDERAL INSPECTION, 1919–1932

From 1919 through 1930, the average production of pork per hog slaughtered under Federal inspection was apparently determined by (A) the quantity of corn available per hog in the season under consideration, by (B) the corn-hog ratio through the previous summer, and by (C) the increasing concentration of hog production in the Corn Belt. The actual and reconstructed weights are compared in D.

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shown in Figure 8, C, this concentration measure gives an adequate explanation of the unexplained variation from B. The actual and the estimated or reconstructed weights are compared in Figure 8, D.

WHY SEASONAL MARKETINGS CHANGE

The reason that hog producers sometimes market as much as 68 per cent of the year's hog supply during the winter season and sometimes as little as 60 per cent, is closely related to the weight problem. When a large corn supply is on hand in the fall, the typical farmer is willing to feed his hogs to heavier weights and to retard the rate of marketing, whereas if the corn supply is short, an early market movement is to be expected. Also, when the corn-hog ratio is low in the summer and early fall, the producer will tend to curtail fall breedings and to market some prospective breeding stock, whereas a high ratio will cause an increase in breedings, with a resultant decrease in the market movement.

A graphic check of this 2-factor explanation of the winter and summer distribution of hog marketings is presented in Figure 9. The same corn supply per hog and May-through-October corn-hog ratio as used in the weight analysis have been used in this analysis. The measure of the percentage of the crop winter marketed has been calculated by expressing the inspected slaughter for October through April as a percentage of the total slaughter for the corresponding October-through-September hog year.

In Figure 9, A, the relation between the percentage of the hog supply winter marketed and the preceding summer Corn Belt corn-hog ratio is shown. The average relation between the two as measured by the diagonal line is negative. In B, the corn supply per hog and the unexplained portion of the winter-marketed percentage from A are related, and a second negative relation is obtained. In C, the estimated percentages as read or reconstructed from the two response curves and the actual data are compared. The agreement between the two is good.

WHY DAY-TO-DAY MARKETINGS CHANGE

The extent to which producers market their hogs in response to short-time or day-to-day changes in the market price may now be considered. Since the short-time response is likely to be made in an effort to obtain an above-average price, the length of time involved in making the response as well as the day-to-day changes in price to which the response is most likely to be made will vary from market district to market district, so that to analyze the short-time marketing response from a nation-wide standpoint is impracticable.

In Iowa, for example, where a great deal of direct buying is done by the local representatives of the larger packers and by the smaller packing plants and where sales quotations or offers may be obtained over the telephone, the day-to-day response of marketings to temporary price changes may be expected to be immediate and direct. The heaviest marketings should tend to come when the day-to-day prices are the highest.

But in the case of a market conveniently located to receive truck receipts from a district serviced by a daily radio market report, such as Sioux City, the short-time response of truck receipts should lag one

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day behind the day-to-day changes in price. This is what actually happens at Sioux City. (Fig. 10.) To obtain the measure of the daily price factor, which is represented on the horizontal scale, the price for each market day was expressed as a plus or minus change in

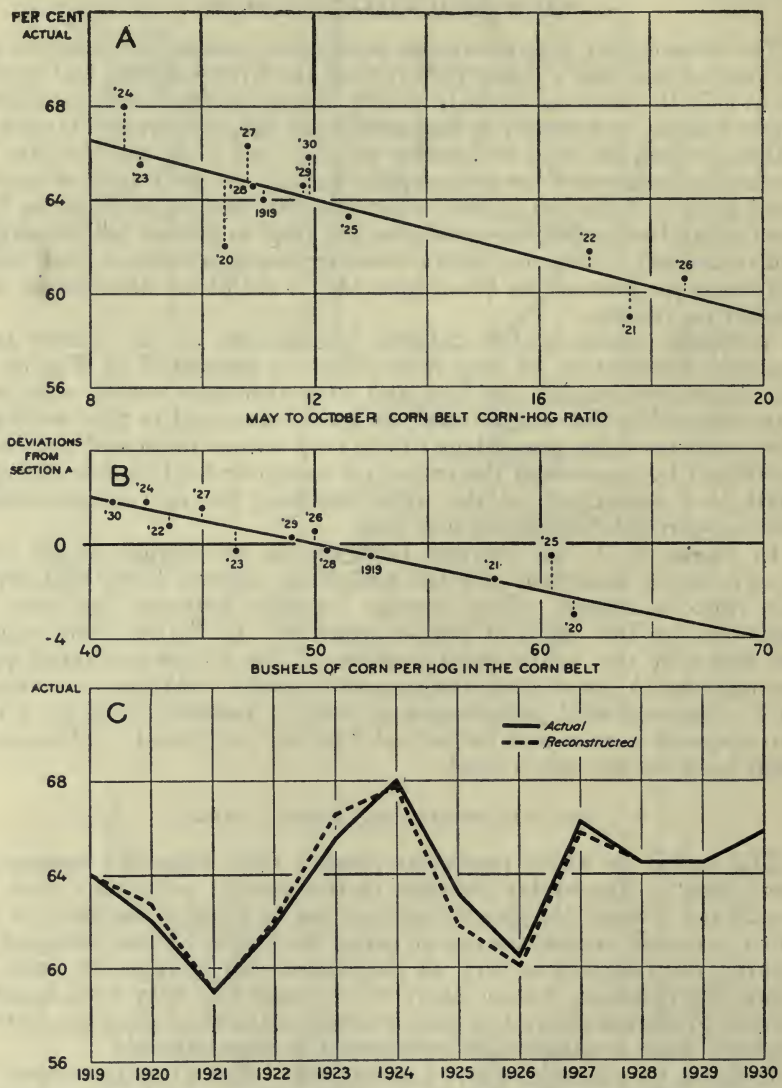

FIGURE 9.—ANALYSIS OF THE SEASONAL DISTRIBUTION OF FEDERALLY INSPECTED HOG SLAUGHTER, 1919–1930

When (A) the preceding summer and early fall corn-hog ratio has been high and (B) the fall corn supply is plentiful, the proportion of the hog-year hog supply winter marketed is below average and when the situation is reversed the proportion is above average. The actual and reconstructed data are compared in (C).

cents per hundredweight from the price of the preceding market day, and to obtain the comparative daily supply measure, which is represented on the vertical scale, the truck receipts for each day were expressed as a percentage of the receipts for the preceding day.

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As indicated by the heavy diagonal curve drawn through the averages plotted on the chart, when the price of medium-weight hogs at Sioux City decreased 20 cents on Tuesday from the preceding Monday level, the truck receipts on the next day, Wednesday, were usually well below their normal level, and when the price moved upward, truck receipts tended to increase.

But in the case of a market which is not freely accessible by truck and which is dependent upon a wide area for its normal supply, a somewhat slower response of marketings to short-time price changes may be expected, since the in-movement must be made by freight train and over a substantial distance.

This is the actual situation in the Chicago market. (Fig. 11.) When the actual changes in price from Saturday to Monday are compared with the percentage changes in total market receipts from Monday to Thursday a marked positive association is disclosed. This relation, based upon a 3-day lag, is the closest that can be obtained

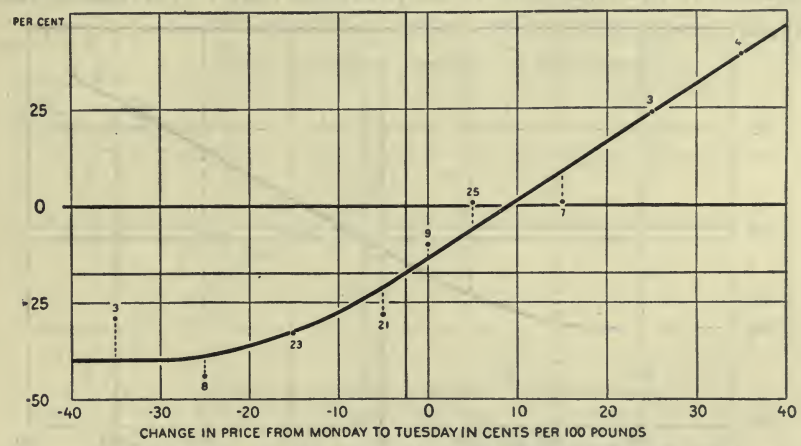

FIGURE 10.—RELATION BETWEEN CHANGES IN PRICES FROM MONDAY TO TUESDAY AND TRUCK RECEIPTS FROM TUESDAY TO WEDNESDAY OF HOGS AT SIOUX CITY, 1929–30

When hog prices move up from one day to the next, farmers living within trucking distance of Sioux City tend to increase their marketings a day later, and when prices move down they tend to decrease their marketings a day later.

by the use of a single price factor; but by the use of a second price factor, the Monday to Tuesday price change, a closer approximation may be obtained. When the receipts at Chicago fell below the line of average relationship, the average price change from Monday to Tuesday was negative, and when receipts were above, this second price change was positive.

Although the results of the analyses included in this section are in good agreement with what was expected and with the work done by Stover (*5*), they are given to indicate an approach to the problem and not as a final solution. The changes in receipts that were analyzed were average changes associated with given price changes. Were each item charted, there would be a very wide dispersion or scatter about the line or curve of average relationship.

To use this type of analysis to forecast daily market receipts at a given market it would be necessary to work with individual rather

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than average data. In addition, one would want to know the influence of the weather factor on the market movement, whether the greater response was made to average or top prices, whether the response was the same on the up swing as on the down swing of the hog-price cycle, and to what extent the response changed from month to month through the year.

WHY MARKET RECEIPTS CHANGE

The next question to consider is the extent to which the nation-wide or mass response so far described is typical of the market-district or individual-producer responses that have been averaged together to obtain the single measure.

Although there are few actual quantitative data with respect to individual producers' responses to price in hog production, there is no doubt but that the exact type and degree of response varies widely from one individual to another. Some evidence, in fact, indicates that from 15 to 20 per cent of the producers may be decreasing their

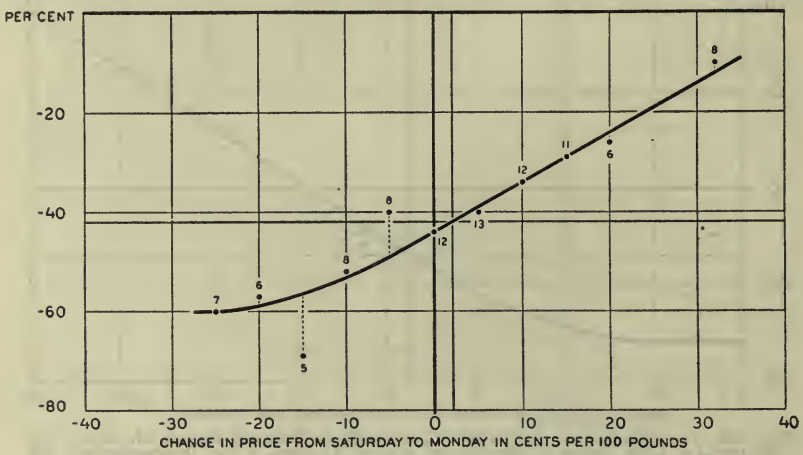

FIGURE 11.—RELATION BETWEEN CHANGES IN PRICES FROM SATURDAY TO MONDAY AND MARKET RECEIPTS FROM MONDAY TO THURSDAY OF HOGS AT CHICAGO, 1929–30

Like truck receipts at Sioux City, daily hog receipts at Chicago show a definite response to short-time price changes but, since freight receipts predominate, the maximum relation is obtained when a 3-day price lag is used.

hog production while between 30 and 40 per cent may be increasing production, with the remaining 40 to 60 per cent making no change.

But in case there are certain economic influences which directly affect the profits that many producers may expect to make in hog production, those influences, when any considerable number of individual cases are summed or averaged, should stand out clearly, whereas the influences of those causal factors that are essentially random in nature should tend to cancel out.

In analyzing market-district data, then, there is good reason to expect that the same general type of relationship will be found as was found in the national analysis. Since the averaging process has not been carried so far in the sectional as in the national data, more variation is to be expected in the sectional data, and certain factors which seemed to have small influence in the national analysis may become important when sectional data are considered.

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As a check upon this general analysis, the changes in the market receipts of hogs at Chicago from season to season may be related to the Chicago price corn-hog ratio. The relationship is as expected.

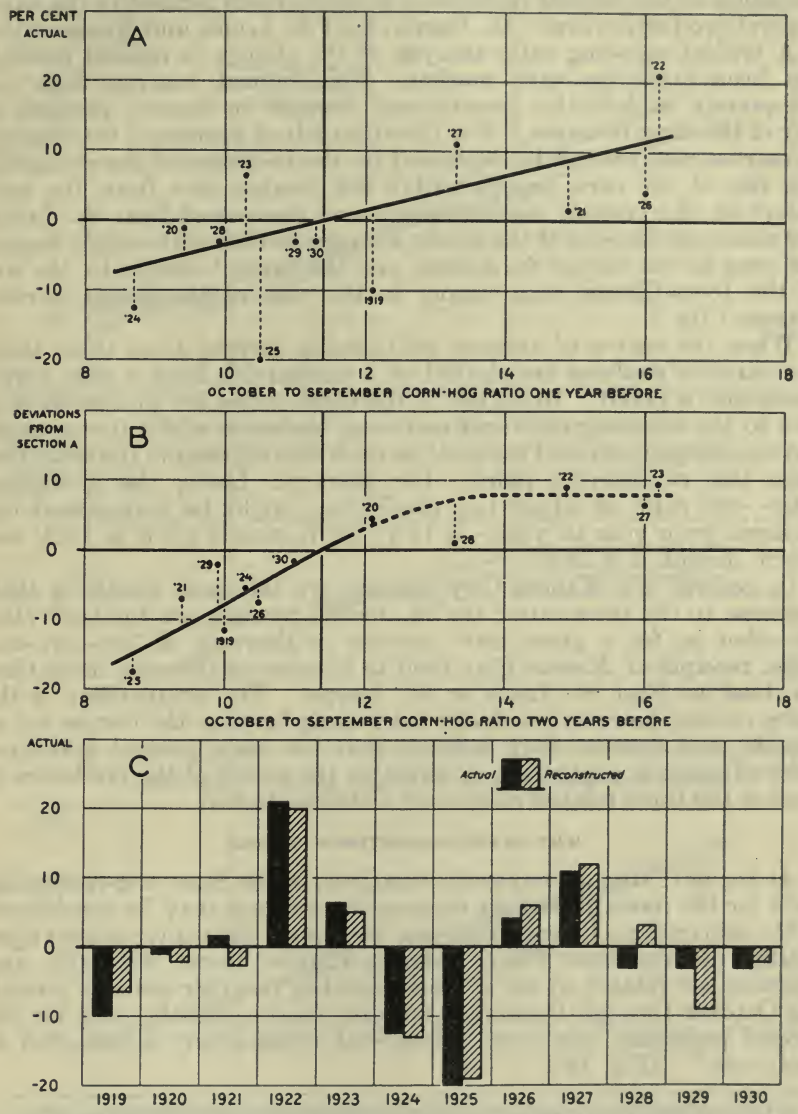

FIGURE 12.—RELATION BETWEEN THE CHICAGO CORN-HOG RATIO AND THE YEAR-TO-YEAR CHANGES IN CHICAGO HOG RECEIPTS, 1919–1930

The year-to-year changes in the market receipts of hogs at Chicago are determined by the same influences (A and B) that determine the year-to-year changes in the total United States inspected slaughter. (See fig. 5.) The actual and reconstructed changes are compared in C.

(Fig. 12.) When the corn-hog ratio is high through the given hog year, Chicago market receipts (which are chiefly drawn from Iowa, Indiana, Illinois, Wisconsin, Minnesota, and South Dakota) may be expected to increase through the next year and the year after. When

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the ratio is low, hog production and subsequent marketings are reduced.[9]

As a further check, a comparative analysis may be made of the variation in the market receipts of three markets located in the same general production area: St. Joseph, East St. Louis, and Kansas City.

A typical corn-hog ratio analysis of the change in market receipts has been made for each market. This typical analysis does not adequately explain the year-to-year changes in market receipts in any of the three markets. But the unexplained portion of the changes in market receipts can be explained by the inclusion of the change in the size of the corn supply within the market area from the year before to the current marketing year in the case of East St. Louis, the change in the size of the 2-year average district corn supply lagged one year in the case of St. Joseph, and the current change in the size of the Iowa-Illinois corn supply in the case of the feeder market, Kansas City.[10]

When the curves of average relationship derived from these three comparative analyses are plotted on a comparable basis a close correspondence is noted. In Figure 13 the three curves are plotted in relation to the corn-hog ratio and corn-crop scales on which 0 represents the no-change point and the scale on each side represents the deviation from this equilibrium point. For East St. Louis, the no-change ratio—the ratio at which hog production might be maintained unchanged from year to year—is 12.4; for Kansas City it is 13.2, and for St. Joseph it is 13.6.

In general, the Kansas City receipts are the most elastic in their response to the price ratio; the St. Joseph receipts are the least elastic—that is, for a given unit increase or decrease in the corn-hog ratio, receipts at Kansas City tend to increase or decrease more than do those at East St. Louis or St. Joseph. The comparison of the three curves, however, is chiefly interesting because the curves are so similar, and because they indicate that the same general influences were effective in controlling or directing the action of the producers in each of the three related marketing districts studied.

WHY STATE MARKETINGS CHANGE

As the next step a comparative analysis of the State hog-marketing data for the more important corn-and-hog States may be considered. If the percentage changes from year to year in the winter-season marketings of hogs from Ohio, Indiana, Illinois, Iowa, Nebraska, and Missouri are related to the average corn-hog ratio for the first preceding October-through-December breeding season and the ratio for the second preceding hog year, a clear-cut relationship is indicated in each case.[11] (Fig. 14.)

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[9] In Figure 12 the percentage changes in the Chicago October-through-September hog-year market receipts from year to year are related to the Chicago-price corn-hog ratio for the first and second hog year before. The corn-hog ratio is based on the average Chicago price of hogs and No. 3 Yellow corn.

[10] The curves in Figure 13 were derived in each case by relating the October-through-September hog-year changes in market receipts from year to year from 1919–20 through 1930–31 to (1) the average October-through-April corn-hog ratio for the district for the first year before, (2) the same ratio for the second year before, and (3) the percentage change in the appropriate corn supply from the supply a year before. The district corn-hog ratios and corn supplies were based upon State farm-price ratio and corn supply data and combined according to the weights given in Table 2.

[11] The State hog-marketing data used in this analysis are special data collected and compiled in the Division of Crop and Livestock Estimates. They were derived from market-receipts and direct-shipment data reported by State of origin, and are subject to some revision. The winter-season marketing used in this analysis were October-through-April marketings from Illinois, September-through-March marketings for Ohio and Indiana, October-through-March marketings for Missouri, and November-through-April marketings for Iowa and Nebraska.

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This average corn-hog ratio is used to simplify the analysis. The assumption involved in the average is that the effect of either of the two corn-hog ratios upon the actual changes in production is equal to

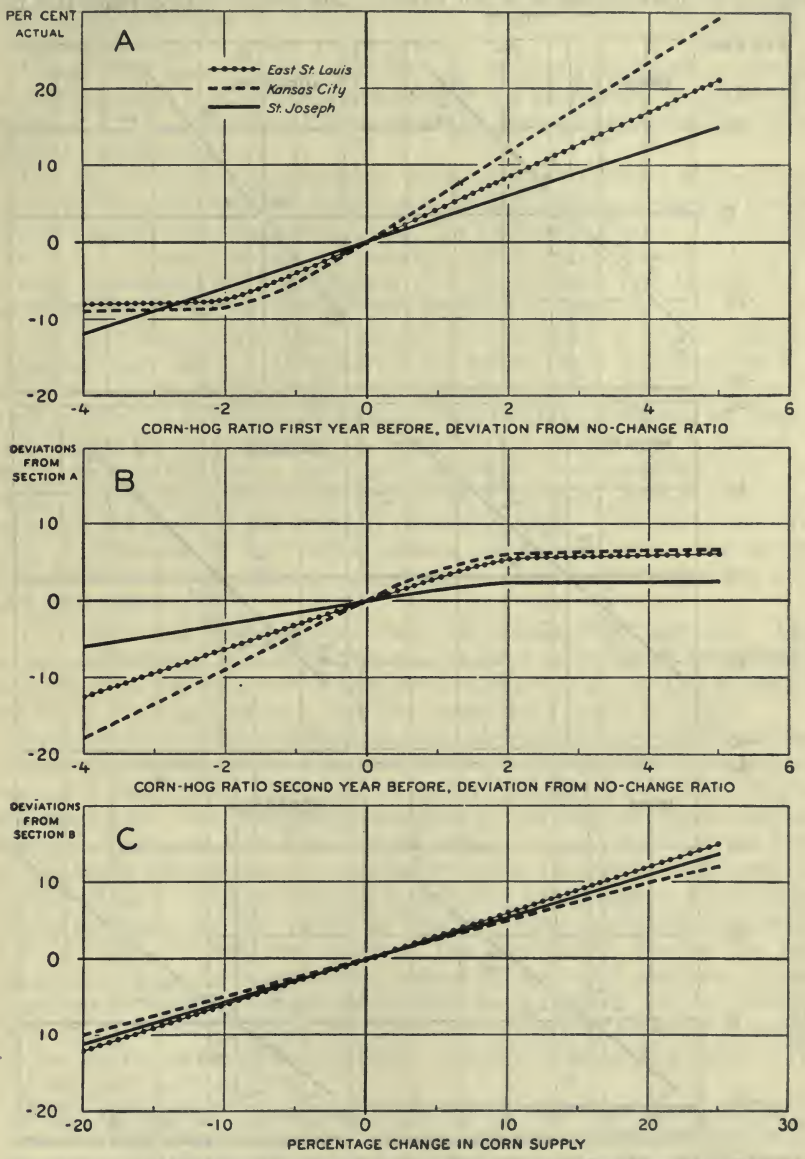

FIGURE 13.—PRODUCER RESPONSE TO PRICE MEASURES DERIVED FROM THREE SEPARATE MARKET ANALYSES

The response curves that describe the relation between (A) the corn-hog ratio the first year before, (B) the ratio the second year before, and (C) the change in the corn supply, and the year-to-year changes in hog marketings at East St. Louis, Kansas City, and St. Joseph are much alike.

the effect of the other. This assumption is certainly not a fixed truth. But since a simple comparative measure that will indicate the approximate relationship is all that is desired, this average ratio

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may be used. Actually, with the exception of the 1921 and 1922 marketings from Ohio, it works very well.

Although the general relationship is much the same in each State, Figure 14 shows that it is not exactly the same. As a rule, the fluc-

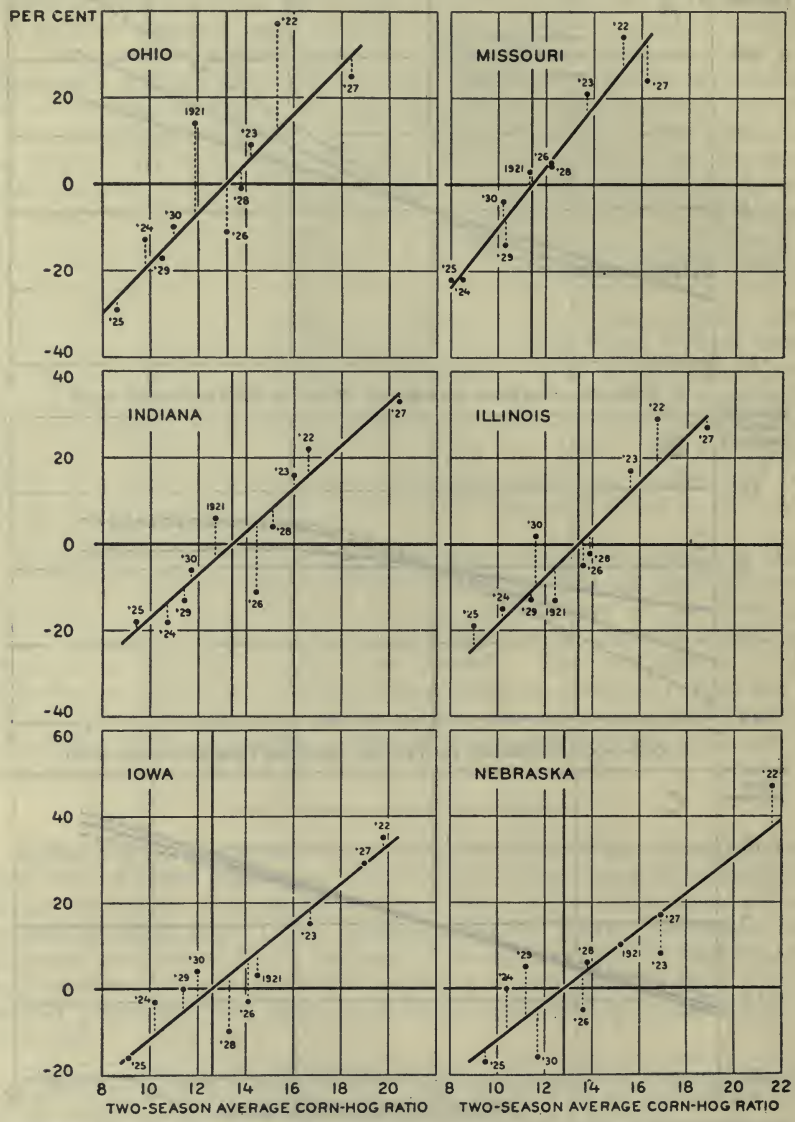

FIGURE 14.—RELATION BETWEEN THE SEASON-TO-SEASON CHANGES IN STATE HOG MARKETINGS AND THE STATE FARM-PRICE CORN-HOG RATIOS, 1921–1930

When year-to-year changes in State hog marketings are related to the average corn-hog ratio for the first breeding season and second hog year before, a good explanation of the changes in State hog marketings from 1921 through 1930 is obtained.

tuation in the marketing measure is within the range of a 20 per cent decrease and a 35 per cent increase. But the distribution of the actual changes within this range is quite different from State to State. In

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Ohio, Indiana, and Illinois there were significant decreases in 5 out of the 10 years considered. In Missouri the increases and decreases were about evenly balanced. In Iowa and Nebraska there were significant decreases in 2 and 3 years, respectively, and significant increases in 5 and 6 years, respectively.

These differences in the distribution of the year-to-year changes are explained in part by the differences in the no-change or equilibrium ratios and in part by the differences in the corn-hog ratios in the States under consideration.

The no-change or equilibrium ratio may be defined as the corn-hog ratio at which hog production would have been expected to remain approximately unchanged through the period analyzed. This ratio (the ratio where the line of average relationship crosses the zero-change marketing line) for Ohio is 13.2; for Indiana and Illinois, 13.4; for Missouri, 11.4; for Iowa, 12.6; and for Nebraska, 12.8.

The corn-hog ratios differ chiefly with respect to the amount of variation they show. In general, the lower limit of the ratios is 9. But the average range of the variation above this lower limit is somewhat greater in Iowa and Nebraska than in Ohio, Indiana, or Illinois.

In short, hog production in Iowa and Nebraska is increased in response to a relatively low corn-hog ratio in comparison with hog production in the eastern section of the Corn Belt, and the corn-hog ratios in the two States average relatively high. The net result has been a decrease in the winter-season marketings from the eastern Corn Belt and an increase in the winter-season marketings from Iowa and Nebraska.

The individual State analyses also differ in another respect. That is, the differences in the slopes of the lines of average relationship indicate that the response of hog production to a given unit change in the State corn-hog ratio is not the same from State to State.

In order to show this difference more clearly, the several State lines of average relationship or response curves, together with a comparable curve for the United States, are directly compared with one another in Figure 15. The percentage changes in the winter-season marketings are represented on the vertical scale, the zero point on the horizontal scale represents the no-change ratio for each State and the United States, and the scale on either side represents the deviations of the several corn-hog ratios in bushels from the no-change point.

To obtain the response measure for the United States, the percentage changes from season to season in the total number of hogs slaughtered under Federal inspection were related to the average Corn Belt corn-hog ratio for the first preceding October-through-December breeding period and the second preceding hog year. The no-change ratio was 12.8.

These comparative measures (fig. 15) indicate that the greatest or most elastic changes in production in response to unit changes in the corn-hog ratio during the period studied were in Ohio and Missouri, and the least elastic were in Nebraska and Iowa. That is, the most elastic responses to a unit or 1-bushel change in the State corn-hog ratio were made in the two States in which the ratio was the least variable, and the least elastic responses were made in the two States in which the ratio was the most variable.

United States production was less elastic than was the production in any of the States considered except Nebraska and Iowa. But

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this less elastic response was to be expected, since Iowa is the most important hog State, since the response in Minnesota and Wisconsin, where hog production is conditioned by butterfat production, is less

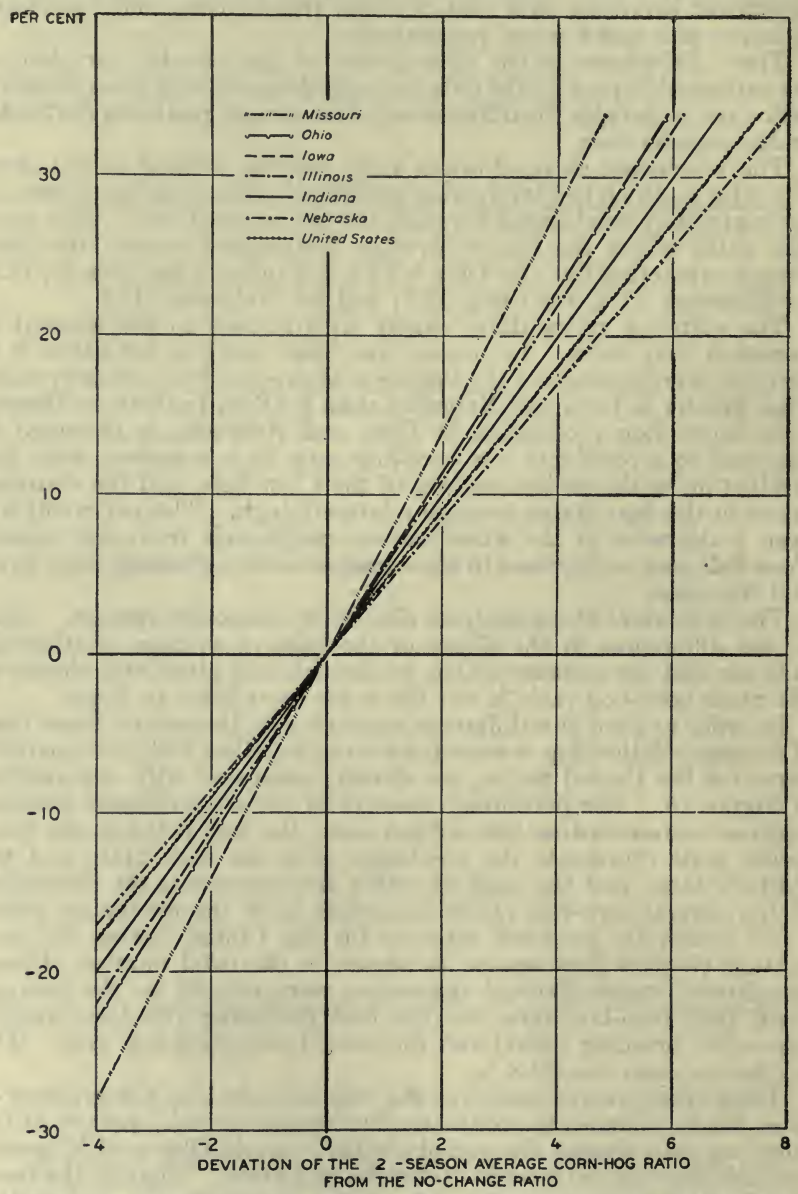

FIGURE 15.—RESPONSE CURVES FOR SIX INDIVIDUAL STATES AND THE UNITED STATES

When the response-of-production-to-price curves for the six most important corn-and-hog States and the United States are compared, the Missouri response is found to be the most elastic and the Nebraska response the least elastic.

variable than in the Corn Belt proper, and since western and southern hog production is not necessarily changed in direct response to the Corn Belt corn-hog ratio.

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WHY AREA MARKETINGS CHANGE

As a last step in the consideration of the problem of the mass response, the analysis of the hog producers' response to price in hog production may now be extended to certain broad type-of-farming areas—to the eastern and western Corn Belt, the dairy section, the Pacific coast, and the South.

THE WESTERN CORN BELT

Since 1920 there has been a double movement toward an increased concentration of United States hog numbers in the Corn Belt and toward a shift in corn production from the eastern part of the Corn Belt to the western part—from Ohio and Indiana to Iowa and Nebraska. An analysis of the western section as a unit, in comparison with a like analysis of the eastern section, should indicate this east-to-west shift of corn and hog production.

In Figure 16, the percentage changes in the October-through-September hog-year marketings of hogs from the western Corn Belt (Iowa, Missouri, South Dakota, Nebraska, and Kansas), have been related to an average composite State or sectional corn-hog ratio for the period from October through March, one and two years before. The average relationship is indicated by the heavy diagonal line.[12]

In 6 years out of the 10 considered, the sectional corn-hog ratio has been above the no-change ratio, and in 4 years below it. The result has been an increase in hog numbers in this section during the period analyzed.

EASTERN CORN BELT

As shown in Figure 16, the average relationship between the year-to-year changes in eastern Corn Belt (Illinois, Indiana, and Ohio) hog production and the appropriate sectional corn-hog ratio is different from the relationship in the western Corn Belt.

Hog production in this eastern section is slightly more elastic or more responsive to the low and medium ratios than is hog production in the western section, but the response to the higher ratios is seemingly more limited. Also, the no-change ratio for the eastern section is 14.6 as compared with 14.0 for the western section. Through the period analyzed, hog production in this section has decreased more when the corn-hog ratio has been low than it has increased when the ratio has been high.

This decrease has been due in part to the increase in competition from the western section and in part to the increased industrialization of the eastern section. The increase in the western corn-and-hog production has lowered prices and has intensified competition. As a result, the farmers in the eastern section have been ready to consider such alternative enterprises as might be available, and the increasing industrialization of the area has provided an alternative by increasing the demand for fluid milk and cream.

THE DAIRY SECTION

An increase in dairying does not necessarily mean a decrease in hog production. In the area just discussed, the increase in the production of fluid milk and cream has tended to displace hogs; but in an area of

[12] The State weights used in calculating this western-section corn-hog ratio and the eastern-section corn-hog ratio which will be referred to in this discussion are given in Table 2.

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very heavy creamery-butter production, the production of large quantities of skim milk may well be expected to stabilize hog production.

An analysis of the hog situation in Minnesota and Wisconsin indicates that the quantity of available skim milk is as important in

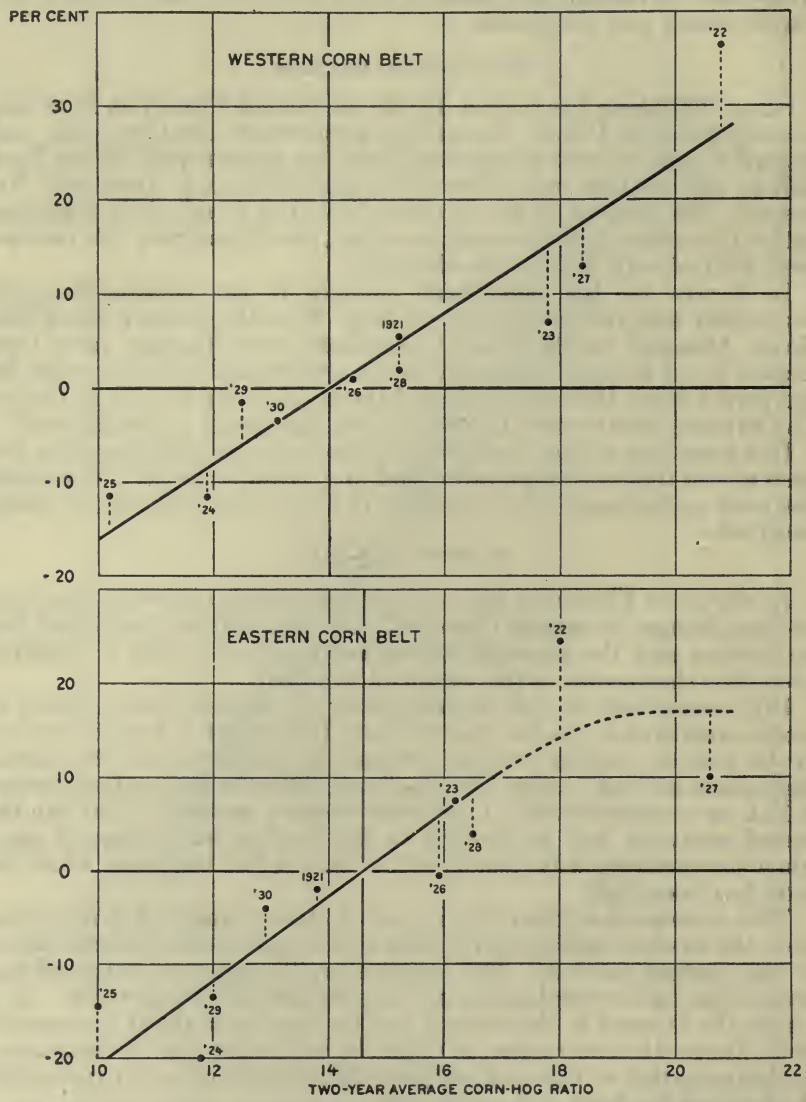

FIGURE 16.—COMPARATIVE MEASURES OF THE HOG PRODUCERS' RESPONSE TO THE CORN-HOG RATIO IN THE WESTERN AND THE EASTERN CORN BELT, 1921–1930

These comparative-response curves indicate an increase in hog numbers in the western Corn Belt in the decade 1921–1930. Hog producers in the western section decreased their hog numbers less when the corn-hog ratio was below average and increased them more when the ratio was high than did the producers in the eastern section.

determining the production of hogs as is the corn-hog ratio. Although the changes in Minnesota and Wisconsin hog marketings from 1919–20 through 1924–25 seem to have been stimulated by the same corn-hog

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ratio influences as were the changes in the more southern Corn Belt States, the combined corn-hog ratio for the two States has moved through a second marked cycle since 1923–24, whereas hog marketings have tended to remain unchanged at the 1923–1925 level.

A partial explanation of this comparative indifference of hog production to the corn-hog ratio in the area under consideration, is suggested by Figure 17. Since 1920 the general level of October-through-September hog marketings has increased almost 50 per cent—from 4,500,000 head per hog year to 6,500,000—while the calendar-year production of creamery butter has apparently increased 100 per cent. If this increase in creamery-butter production from the 200,000,000-pound level in 1920 to the 400,000,000-pound level in 1926–1930 is accepted as indicative of the quantity of skim milk available for hog production in Minnesota and Wisconsin, a simple explanation of the year-to-year changes in their hog production is indicated.

From 1921 to 1924 hog numbers responded freely to the favorable corn-hog ratio and to the increase in available skim milk. In 1924–25

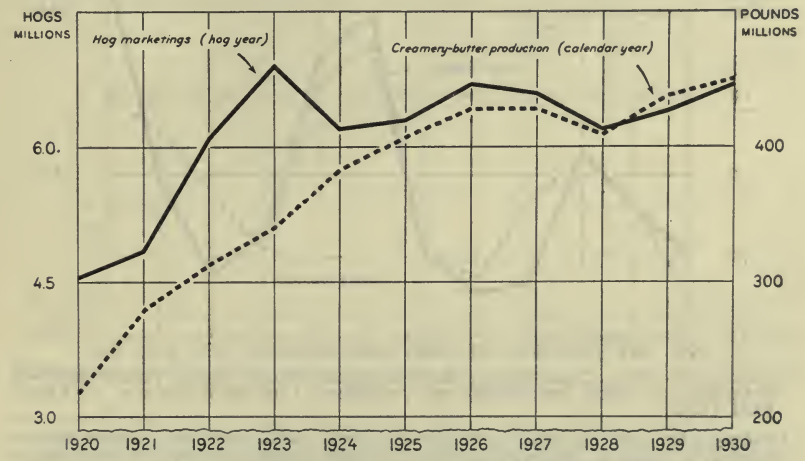

FIGURE 17.—MINNESOTA AND WISCONSIN HOG MARKETINGS AND BUTTER PRODUCTION, 1920–1930

From 1920 through 1924 the corn-hog ratio was an important factor in determining the hog production of the dairy section; since 1925 the production of skim milk as measured by factory-butter production has apparently been the dominant factor.

hog production started downward but soon reached the milk-supported level. As a result, hog production in the two important butter-producing States has tended to remain approximately unchanged since 1925. In short, an increasing production of creamery butter in Minnesota and Wisconsin, in response to a favorable price situation, has tended to absorb the corn production and to place hog production upon a corn-and-skim-milk base.

THE PACIFIC COAST

So far the analyses presented have dealt almost entirely with hog production within the Corn Belt. It is also worth while to consider why hog numbers change in an area which is at least semi-independent of the Corn Belt proper.

The farm price of hogs in California is often above the eastern price. (Fig. 3.) This is on account of the freight charge between the Pacific

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coast and the Corn Belt and the scarcity of the local supply relative to the effective demand. Still, although somewhat different from the Chicago or Iowa price, the California price is closely related to them and usually changes in the same direction and to approximately the same degree that they do. This general agreement, in turn, indicates that the California price is controlled by the same influences as the Corn Belt price and that in case the California producer is responsive to price changes he is seemingly responsive to the same fundamental influences to which the Corn Belt producer is responsive.

As barley is the most important feed grain on the Pacific coast and as California is the most important hog-producing State, the average California barley-hog ratio [13] for from 4 to 18 months preceding is compared with the year-to-year percentage changes in the estimated January 1 number of hogs on farms in California, Oregon, and Wash-

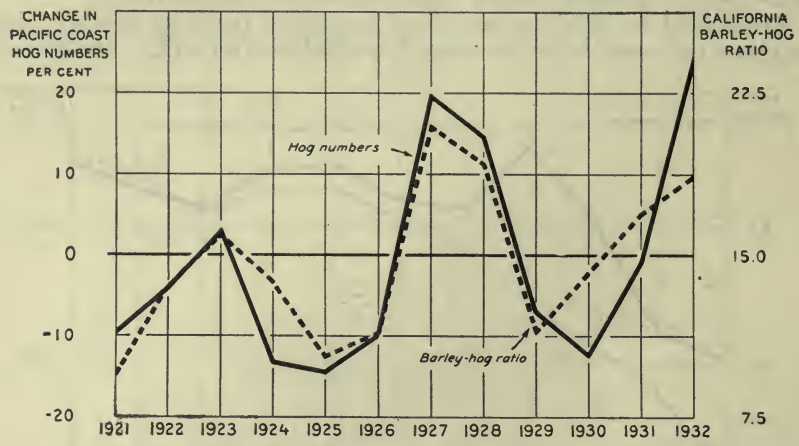

FIGURE 18.—THE CALIFORNIA BARLEY-HOG RATIO AND YEAR-TO-YEAR CHANGES IN HOG NUMBERS ON JANUARY 1 IN THE PACIFIC STATES, 1921–1932

As barley is the most important Pacific-coast feed grain, Pacific-coast hog producers tend to respond to changes in the barley-hog ratio in the same manner that Corn Belt producers respond to changes in the corn-hog ratio.

ington from 1921 through 1932 in Figure 18. The general relation between the two is easily apparent.

Actually, the production of hogs in the Pacific-coast area is responsive to many influences beside this simple single ratio—to wheat prices, to a small quantity of available skim milk, and to actual or prospective corn prices or supplies. But since the barley-hog ratio is closely related to the corn-hog ratio, this simple relation between changes in January 1 hog numbers and the preceding barley-hog ratio indicates that the Pacific-coast hog producer is in part responsive to the same economic influences as the Iowa producer.

THE SOUTH

Although the Corn Belt is the most important commercial hog-producing area in the United States, there are approximately

[13] The term "barley-hog" ratio as used in this bulletin is used to refer to the number of bushels of barley required to buy 100 pounds of live hogs and is computed by dividing the per hundredweight hog price by the per bushel barley price. The barley-hog ratio charted in Figure 18 is based upon the farm prices of barley and of hogs in California.

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10,000,000 head of hogs in the Cotton Belt which supply the major portion of the pork and lard consumed in the South.[14]

In the Corn Belt the hog crop is largely dependent upon the corn crop; and—even though the southern producers have peanuts and certain pasture crops that will supply hog feed—since the corn enterprise is the main feed enterprise in the South, the southern hog crop may be expected to be largely dependent upon the southern corn enterprise.

Actually, the year-to-year changes in southern corn production give a good explanation of the year-to-year changes in southern hog numbers on January 1. But an equally good and much simpler explanation may be secured by relating the corn acreage in the South to the number of hogs on hand on January 1 of the following year. (Fig. 19.)

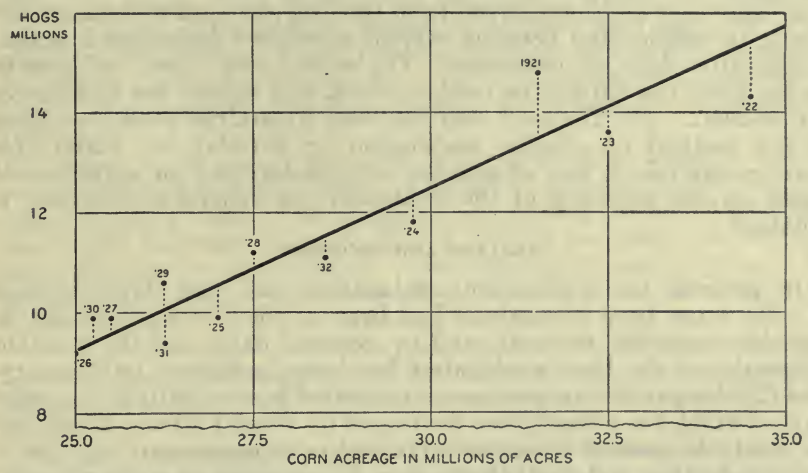

FIGURE 19.—RELATION BETWEEN CORN ACREAGE AND HOG NUMBERS ON JANUARY 1 IN THE COTTON BELT, 1921–1932

From 1920 through 1932 the variation in southern corn acreage has been closely related to the variation in southern hog numbers on hand the following January 1. The variation in corn acreage can be explained, in turn, by the concurrent variation in cotton acreage.

The variation in the southern corn acreage can, in turn, be almost altogether explained by the concurrent changes in the southern cotton acreage. But cotton-acreage changes can also be explained by changes in the price of cotton. So, in the end, hogs and cotton are found to be related.

That is, when cotton prices are low in the late fall and early winter, the cotton producer is evidently inclined to plan on an expanded corn acreage and a contracted cotton acreage the next spring. As a result, he is inclined to increase the size of his spring pig crop and, if corn acreage is increased, his succeeding fall pig crop. As a result the number of hogs on hand on the following January 1 is increased. If, on the other hand, cotton prices are high, the producer's reaction is exactly reversed.

[14] The States included in this analysis are: Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Texas, and Oklahoma.

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EVALUATION OF ANALYTIC METHOD USED

Thus far, interest has been centered in the problem of analyzing and measuring the short-time, seasonal, and year-to-year responses of hog production and marketings to changes in hog prices, corn supplies, and the corn-hog ratio. Some consideration is now in order of the question whether the analytic method used has been adequate.

THE METHOD USED

In general, the method has been: (1) To present a brief qualitative analysis of the particular problem under consideration. This analysis has been based upon experience, observation, and consideration of certain relevant data and has been used to derive a generalized explanation of the phenomena under investigation. (2) To test the qualitative explanation derived from the first step and to measure the degree of relationship between certain associated phenomena, actual quantitative data are necessary. The second step, then, has been to decide upon the data to be used to check and extend the qualitative explanation. (3) The next step has been to analyze these data by a simple method of graphic association or correlation. From this graphic analysis, a line of average relationship and an approximate check on the accuracy of the qualitative or general explanation is obtained.

ANALYSIS AND CRITICISM

In general, the qualitative explanation has been brief because (1) the same type of analysis has been applied to nation-wide, to individual market, to State, and to sectional data, and the constant reiteration of the basic explanation has been considered unnecessary; and (2) the qualitative analysis as presented is substantially the same as that which has already been developed by Wright (*8*) and Elliott (*2*). In short, the general principles advanced in explanation of changes in hog production and marketings may be accepted as approximately correct.

The next point to consider is whether the 10 to 12 year postwar period was a sufficiently long period to analyze for the purpose of this study. The decision must depend upon the objective toward which the study is aimed. In so far as the study is intended to check a general explanation of why hog production changes from time to time, and to indicate the degree of truth included in the general explanation, the period analyzed is sufficiently long. Again, in so far as the objective is to measure the significant differences in response that have existed between different States and market areas and type-of-farming regions, and to serve as an indicator of the reasons for observed differences and likenesses, the period analyzed is long enough.

But if the objective is to develop lasting numerical measures and exact forecasting formulæ, the period analyzed is much too short. The question involved here, however, is not a simple question of time. There is reason to believe that an analysis of a much longer period would have been equally futile for this purpose since the entire price system was subjected to certain influences through the war period which may be considered as unusual, since many of the available prewar data are relatively unreliable, and since the constant injection of new influences and modification of old influences in the price-and-production system make the extension of any economic analysis an inexact procedure.

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Actually, there is a triple purpose in making the graphic analyses—to test the general explanation and to consider the problem of differential responses, to approximate a quantitative explanation, and to develop and explain a simple method of economic analysis which is perhaps more exact than the usual rather generalized method, which can easily be extended or reworked, and which can be used to help forecast future production and marketing phenomena.

Innumerable factors influence economic prices and price responses. All that can usually be done with the inexact and limited data available is to use them to support and supplement general theoretic or qualitative analyses and to give an approximate statistical description of the major relationships involved as they have existed in the past.

The method of graphic analysis used is primarily a method of curve fitting by means of an abbreviated process of successive elimination. A much more mathematical method could have been used, but if the number of cases is small and the fitted lines or curves are admittedly subject to a considerable degree of error, no great advantage is obtained by the substitution of mathematical formulæ for the free-hand-curve technic.

A usual second step in this type of analysis is the calculation of the correlation coefficient or index. This index, since it ranges from 0 in cases in which there is no apparent association between the factors studied, to 1 in cases in which there is perfect association, is an excellent comparative index or scale. But since the greater number of the correlations shown in this study are high, no attempt has been made to calculate every possible correlation coefficient or index.

As it is understood that the quantitative relationships that have been developed are simply approximate measures, the next point to consider is to the extent to which they are reliable with respect to the future.

No objective measure can be obtained. Economic time-series analysis can hardly be supported from an orthodox statistical standpoint. The correlation method has been adapted to a new use, and the value of the method in the new use must be judged with reference to the actual universe in which it is being used. The extension of results obtained from the analysis of historical time-ordered data to the future, must depend upon the extent to which the analysis has properly considered and evaluated the effect of all the important factors in the situation, and the extent to which the phenomena analyzed are subject to that dynamic element, economic change.

A failure to consider an important element in an economic analysis will naturally tend to vitiate the future usefulness of the analysis. In using short-time data, the greatest danger in this direction is the tendency of certain factors—as, for example, the price of wheat and other small grain relative to the price of corn or the general price level—to exercise an approximately constant influence through the time period analyzed. As a result, such constant factors appear to be inoperative and are necessarily neglected since the most important portion of the analytic process is the matching of changes and differences against other changes and differences.

The measurement of the dynamic factor is more uncertain and more subject to error than is the measurement or estimation of the allowance that should be made for apparently constant values or inoperative influences. The direction and general nature of the effect to be expected when certain normally constant factors do become

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active can be estimated with some success. The true dynamic element, which is the new and the unexpected, can not be dealt with until it has appeared.

In general, however, there is good empirical reason to believe that human nature remains approximately unchanged through time and that the actual rate of economic change is usually slow. The best method of economic analysis with respect to the problem of future extension is to decide, through the use of historical data and statistical analysis, what may be expected to take place provided the historical pattern is repeated; to consider what new influences will apparently be operative in the new situation; and to modify the historically derived forecasts to allow for such adjustments and changes as seem most rational. In short, if such analyses as have been developed in this study are to be extended into the future, they must be modified by a well-informed and rational judgment. And, if they are to be used in actual extension or outlook work, they should be reworked and revised from year to year.

THE INDIVIDUAL PRODUCER AND PRICE

In the past, studies of the producers' response to price in hog production have been made from a collective or mass-response viewpoint just as have the analyses presented up to this point. This collective response, made up of several million individual responses, is the final supply-and-price determining force, but in order to understand and to control it, the individual responses themselves must be understood and controlled.

THE INDIVIDUAL UNIT

It is generally known that the producers' responses are not the same from farm to farm, but it is not known whether certain classes of producers are more responsive to price than are certain other classes. That is, it is not known whether the variation in the individual producers' responses to the given price situation is related to a relatively small number of measurable influences or to a large number of special influences which change from farm to farm and from time to time.

In order to control hog production or to apply any farm-relief plan, however, the individual producer must be influenced. And the more that is known about the influences which condition the individual producer responses, the more exactly can the control or relief plan be worked out.

Certain of the questions implied in this discussion can not be answered until data have been accumulated on the individual responses of a large number of individual producers as made through a considerable period of time, but an approximate answer to some of them can be obtained from the more general data which are now available.

ANALYSIS OF INDIVIDUAL RESPONSES

Twice each year, the United States Department of Agriculture, in cooperation with the Post Office Department, conducts a rural-mail-carrier survey in which between 50,000 and 75,000 farm records are obtained. Each farmer is asked to list as of June 1 or December 1 the number of acres in his farm, the number of sows that farrowed on the farm, and the number of pigs saved in the farrowing period just finished and in the same period one year before, and the number of

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sows that have been bred to farrow in the spring or fall period just ahead.

The cards upon which these individual data are listed are concentrated in the offices of the State statisticians, are edited, and tabulated. These tabulations are brought together in the central office of the Department of Agriculture, and a national tabulation and report are prepared. This report, when correctly interpreted, provides a fair estimate of the changes in the number of hogs on farms from time to time and the year-to-year changes in the producers' breeding or production intentions.

From the nine sets of reports that have been released from 1923 through 1931, or from a rearrangement of the data which entered into them, a considerable amount of information with respect to the individual producer's year-to-year changes in production may be obtained. In the present analysis, this information will be used to decide (1) whether the fall-farrowed pig crop is more or less variable than the spring-farrowed crop, (2) to what extent the average change in the size of the pig crop from season to season is representative of the

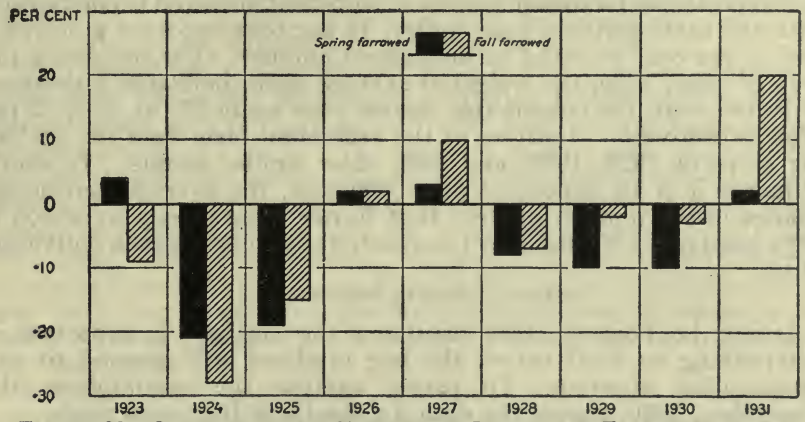

FIGURE 20.—CHANGES IN THE NUMBER OF SOWS THAT FARROWED IN THE SPRING AND THE FALL IN THE UNITED STATES FROM YEAR TO YEAR, 1923–1931

From 1923 through 1931 the year-to-year changes in spring and fall farrowings, as reported in the pig survey, were about equally variable.

individual changes which enter into it, and (3) whether the men with the larger brood-sow herds change their production more or less than do the men with smaller brood-sow herds.

SPRING VERSUS FALL PIG CROP

To decide the first point, the reported number of sows farrowed each spring and each fall has been expressed as a percentage change from the number farrowed a year earlier, and the two series compared. (Fig. 20.) Through the 9-year period considered, the average year-to-year change in the number of sows that farrowed in the spring has been 9 per cent, and in the number that farrowed in the fall, 11 per cent.

The fall pig crop was somewhat the more variable. But since the fall pig crop is not more than 50 per cent as important as the spring pig crop, and since the difference in variability between the two series

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is small, it may be concluded that the observed difference is of limited significance. And since the greater portion of the changes in either crop may be accounted for by changes in corn supplies, hog prices, and the corn-hog ratio, it may also be concluded that the two crops are about equally responsive to the price situation.

THE AVERAGE CHANGE

The pig-survey data as released, are in terms of weighted percentages, that is, in terms of percentage changes in the total number of sows that farrowed or that are to farrow in comparison with the total number that farrowed a year earlier. If, instead of the weighted data being used, the individual farms included in the survey are listed as increasing, decreasing, and no-change farms with respect to the number of sows that farrowed, information can be obtained as to how representative the weighted or reported average is of the individual responses which enter into it.

For the spring pig crop of 1929, when the weighted average indicated a decrease of 10 per cent, of the 70,204 farmers who reported, 27 per cent reported an increased number of sows that farrowed in comparison with the same period a year earlier, 41 per cent reported a decrease and 32 per cent reported an unchanged number. For the spring pig crop of 1930, when the weighted average again indicated a decrease of 10 per cent, the comparable figures were again 27, 41, and 32 per cent respectively. Analyses of the individual farm data for the fall pig crops of 1926, 1929, and 1930 show similar results. In short, although it is an important price influence, the average percentage change in the number of sows that farrow from season to season is not a good index of what may be expected to happen on each individual farm.

EFFECT OF SIZE OF THE SOW HERD

It may be, however, that the size of the sow herd is important in determining to what extent the hog producer will respond to any given price situation. To partly analyze this assumption, the December, 1926, pig-survey data for the Corn Belt were used.

In December, 1926, 37,144 Corn Belt hog producers included in the pig survey reported that they had 236,532 sows that farrowed in the spring of 1926 and that they intended to have 249,754 sows farrow in the spring of 1927. This indicated an average increase of 5.6 per cent.

When the data were broken down and classed with respect to the size of the sow herd, a marked relation was found. Three thousand nine hundred and thirty-nine producers who had no sows that farrowed in the spring of 1926 indicated an intention to have 10,405 sows farrow the next spring. That is, the men with no sows in the spring of 1926 intended to have enough sows farrow in the spring of 1927 to account for almost 80 per cent of the actual increase indicated.

For the other producers the relation between the number of sows that farrowed in the spring of 1926 and the number to farrow in 1927 was:

Those with 1 to 5 sows expected to increase 23.1 per cent.
Those with 6 to 10 sows expected to increase 6.4 per cent.
Those with 11 to 15 sows expected to decrease 0.8 per cent.
Those with 16 to 20 sows expected to decrease 2.7 per cent.
Those with 21 to 25 sows expected to decrease 8.2 per cent.
Those with 26 to 50 sows expected to decrease 20.7 per cent.

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Apparently, there was a marked relation between the size of the sow herd and type and extent of the price response which the hog producer expected to make. In part this is a significant relation, but in part it is the result of the fact that a hog producer can only increase the size of his sow herd by units of one sow.

In 1926 hog prices and the corn-hog ratio were high. In fact, the price situation had been favorable enough in the fall of 1925 to cause a small increase in the size of the 1926 spring crop over the 1925 crop. A large number of small producers decided to respond to a seemingly very favorable price situation by increasing the size of their sow herd. But even for a man with two sows, a 1-sow increase would mean a 50 per cent increase. Any general movement among the small producers toward either an increase or a decrease must result in a very large percentage change in their production because of the small base from which the change is made.

This was the case in the fall of 1926. The men with between 6 and 10 sows in the spring indicated an intended increase which agreed fairly well with the average. But the men with 5 or fewer sows indicated a large percentage increase since each intended to increase by about 1 sow. The men with the larger size sow herds, on the other hand, indicated an intention to decrease.

But, aside from the question of the 1-sow change in relation to a small base, the extent to which the relation in the 1926 data is of general significance is questionable. The data examined were in part intentions-to-farrow data. To secure a more exact measure, the number of sows that farrowed in the spring of 1927 should have been compared with the number that farrowed in the spring of 1926. Again, the data examined were for a single year, actually, the data for a decade should be analyzed. It is possible that the 1927 farrow data would have shown a much more even reaction. Or it is possible that the larger producers made larger-than-average increases in the spring of 1926. In short, no definite conclusion can be drawn from the available data.[15]

Although there may be no herd-size group which is especially responsive to price, there might be enough hogs on the large farms or in the large herds so that in terms of absolute numbers a small minority of the hog producers might be able to control production. Apparently there is not.

An analysis of the relation between the acreage of the farm and the associated size of the sow herd indicates that, although there is a positive relation, the actual degree of association is small. In general, either a small or a large farm may have no hogs, but the larger the farm the larger the hog herd which may be economically fitted into the farm organization. This is what is found in actual practice. The smaller farms have small to medium sized herds and the larger farms have small to large sized herds.

Since no herd-size distribution is available in either census or crop-estimates data, 37,144 farm-survey cards from the December, 1926, pig survey for the 10 Corn Belt States have been grouped with respect to the number of sows that farrowed per farm in the spring of 1926 in order to obtain such a frequency distribution. This dis-

[15] For the most part, the conclusion reached in this study agrees with that reached by Thomsen and Richards (*6*) in Missouri and with certain work done by F. K. Reed in the Division of Crop and Livestock Estimates. Thomsen and Richards, however, found a positive relation between the size of the sow herd and the increase in fall farrowings from the year before in 1927 and 1928.

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tribution included 236,532 brood sows and is shown graphically in Figure 21. The size of the sow herd is represented on the horizontal scale, and the actual number of sows held in each size group is measured on the vertical scale. The median or half-way mark is, as indicated by the heavy broken upright line, between the 11 and 12 sow size groups. This means that one-half of the brood sows in the selected sample were held in herds of 11 or less and one-half in herds of 12 or more.

For the United States as a whole, this half-way mark must necessarily be even lower. In Iowa one-half of the sows in the sample were held in herds of 15 or less; in Ohio one-half were held in herds of six or less. Were the less important hog-producing States considered, the Ohio type of distribution, which indicates that the large majority of the sows are held by the small producers, would be expected. Also,

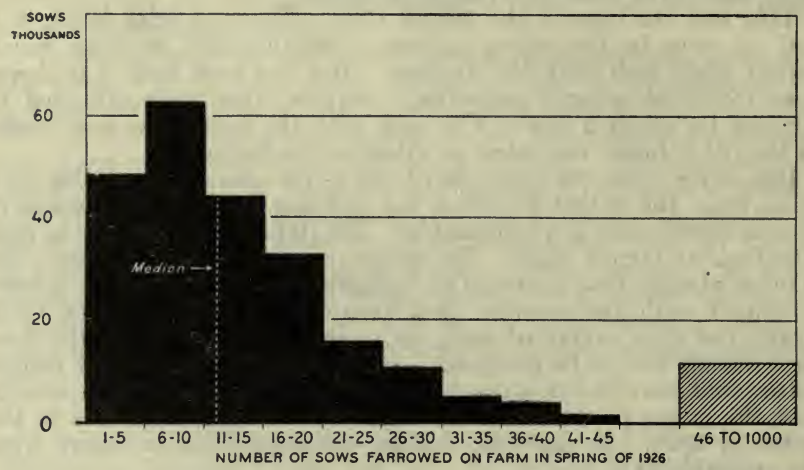

FIGURE 21.—FREQUENCY DISTRIBUTION OF 236,532 CORN BELT SOWS IN THE SPRING OF 1926 BY SIZE OF HERD

In the spring of 1926 approximately one-half of the sows that farrowed in the Corn Belt were on farms where 11 or fewer sows farrowed.

this half-way mark or median-size herd presumably varies from time to time as hog production is increased or decreased.

Although the distribution of brood-sow holdings as shown in Figure 21 is not an exact distribution, it does furnish an additional bit of evidence that the changes in the hog production of the United States from year to year are not dominated or caused by the action of any one special group of large-herd men.

ADJUSTMENT OF PRODUCTION TO DEMAND

Since the individual hog producer is interested in obtaining a maximum profit from his farm or, more exactly, a maximum price for his combined productive resources and since the statistical demand or supply-price curves such as the one shown in Figure 3 generally indicate that a large national hog supply may be expected actually to sell for a smaller gross value than a smaller supply, a great deal of emphasis has been placed upon the idea that "production should be adjusted to demand." The next step in this analysis is the consideration of the problem of planned production.

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It was found, as supply situation after supply situation was worked through, that the chief factors affecting hog supplies were hog prices, corn supplies, and corn prices. Since hog prices are in part made by hog supplies and since corn prices are largely dependent upon corn supplies, an investigation of the long-time relation between corn and hog supplies should be worth while.

CORN SUPPLIES AND HOG SUPPLIES

The annual estimated commercial slaughter of hogs in millions of head and a 2-year moving average of United States corn production are plotted together in Figure 22, for the 51-year period from 1880–81 through 1930–31. In both series a marked upward trend is evident. Through the period, however, hog production has apparently increased

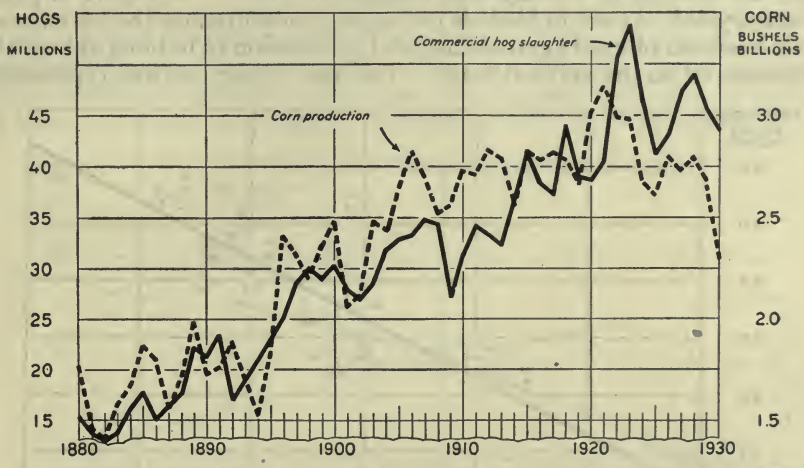

FIGURE 22.—COMMERCIAL HOG SLAUGHTER AS COMPARED WITH A 2-YEAR AVERAGE CORN SUPPLY, 1880–1930

Between 1880–81 and 1930–31, United States corn and hog production have moved through eight major cycles together. Although the commercial slaughter has increased more rapidly than has the corn supply, the year-to-year changes in corn production are evidently important in determining the year-to-year changes in hog supplies or slaughter. Commercial slaughter is equivalent to federally inspected slaughter.

approximately 200 per cent, while corn production has increased only 80 per cent.

This apparently more rapid increase in hog production has been largely caused by a shift from farm to commercial slaughter. The better figure to use as a hog index might be the estimated number of all hogs on farms on January 1. On January 1, 1881, there were approximately 36,000,000 hogs on hand; on January 1, 1931, there were approximately 54,000,000 head. This 50 per cent increase is well in line with the actual increase in corn production.

For a year-to-year measure of change, however, the commercial slaughter series is the best measure available. The 2-year average corn supply (plotted on the second year) has been used, since hog production is influenced by the supply for both the first and second year before. In the 51-year period ended in 1930–31, there were eight distant cycles in the 2-year average corn supply. Each time there has been a corresponding change in hog slaughter. That is, the cyclic changes in hog production can be explained in part by the cyclic changes in corn production. The long-time trend in corn

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production, in turn, is to be explained in part by the increasing demand for pork and lard.

This general statistical correspondence between the long-time trend and the cyclic elements in corn production and hog slaughter or hog numbers, together with the general dependence of changes in hog production and seasonal marketing distribution and weight upon corn supplies, indicates that corn production and hog production are closely related. This, in turn, suggests that the hog producer, who is usually a corn producer, must be able to control corn production if he is to control hog production.

WHY CORN PRODUCTION CHANGES

The two immediate causal factors behind changes in corn production are changes in acreage and changes in yield. In Figure 23, the average yield, of corn in bushels per acre as measured on the horizontal scale has been plotted against the total production in billions of bushels as measured on the vertical scale. The heavy diagonal line represents

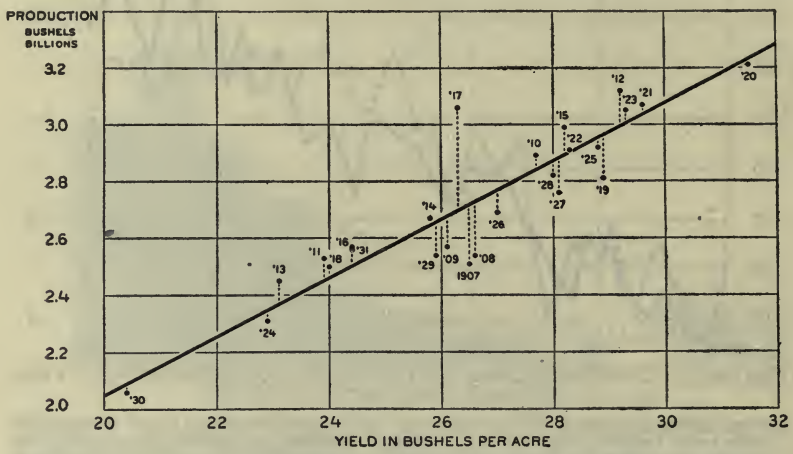

FIGURE 23.—RELATION BETWEEN UNITED STATES CORN PRODUCTION AND CORN YIELDS, 1907–1931

As corn yields change in response to cultural and climatic changes, corn production necessarily changes. From 1907 to 1931, United States corn acreage changed so little that the year-to-year changes in corn production may almost all be explained by yield changes.

the production which would have resulted had acreage been held constant at 102,500,000 acres and had yields varied as they actually did.

As indicated by the close agreement between the actual production and the fixed acreage relationship in the chart, the important factor behind the variation in the size of the United States corn crop through the last two decades has been the yield factor. In only one of the 25 years considered, 1917, was the change in acreage the major determinant of an important change in the size of the crop. The average yield, unfortunately, is for the most part a composite measure of many weather factors which are not economic in nature and over which the farmer has no control.

ALTERNATIVE ENTERPRISES

Provided that a more stable hog-price-and-production system is desirable, the hog producer, by learning what current corn and hog prices mean instead of only considering what they are, may be able

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to eliminate that portion of the variation in hog production which is directly related to price. The real problem, however, is concerned with that portion of the variation in production which is related to the variation in the physical size of the corn crop.

In the Corn Belt, where the greater portion of the corn crop is raised and where the greater portion of the commercial hog marketings originate, the corn crop apparently has a very decided comparative advantage over any other major crop. But the size of the crop is subject to a marked variation because of the variable-yield factor. When the crop is large, the above-average portion can most easily be fed to hogs and marketed as pork; when the crop is small, the below-average production can be most easily adjusted for by a cut in hog numbers.

The alternative to this expansion and contraction of the hog enterprise is either corn storage on a large scale or the expansion or contraction of some other enterprise. To date, there has been no move toward stabilization of the corn supply through any considerable period of time by means of storage. Meanwhile, in Figure 24, three tenta-

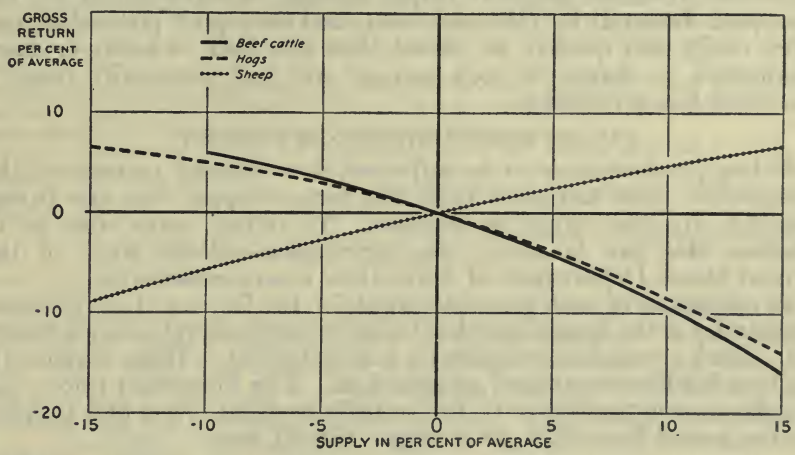

FIGURE 24.—RELATION BETWEEN THE TONNAGE OF LIVESTOCK MARKETED PER YEAR AND THE GROSS RETURN TO THE PRODUCERS

On an average, from 1921 through 1931, an increase in the annual market supply of hogs or of beef cattle resulted in a decrease, and an increase in the supply of sheep in only a small increase, in the collective producers' gross income and a decrease in marketing resulted in an increase in the gross income.

tive curves of gross return in relation to gross output or supply are presented, which show what the farmer may expect when marketings of beef cattle, of hogs, or of sheep are increased or decreased provided the general price level and consumer demand influences remain unchanged.[16]

As the supply marketed (measured on the horizontal scale) is increased, the gross return to hog producers is decreased. The same thing is true of beef cattle. In the case of sheep, however, as the supply marketed is increased, the gross return is increased. But a relatively large increase in sheep marketings is required to obtain a

[16] These gross-return curves have been derived from supply-price curves which represent the net relation between the tonnage slaughtered under Federal inspection and the average price received per live hundredweight after the influence of pay rolls (as measured by the Federal Reserve Board's index) has been allowed for. They are based upon data for the period from 1921 through 1931 and are not to be considered as either exact or final.

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small increase in gross income; and sheep, from the standpoint of quantity of meat produced, are relatively unimportant in comparison with hogs or beef cattle. In addition, to increase the production of either beef cattle or sheep in a short time is not so easy, even if possible, as to increase hog production.

Butterfat production is important in the Corn Belt. No definite data are available, but it is probable that the gross-return curve for butterfat is more elastic, that is, an increased supply would cause a smaller value decrease or an increase, than are the livestock curves shown in Figure 24. Within the last decade, the dairy enterprise has steadily gained ground in the Corn Belt. But the dairy enterprise is essentially a stable enterprise, and it is not to be expected that changes in corn production in the Corn Belt within the next decade will be counteracted by changes in dairy production to such an extent as to stabilize hog production.

Of course the corn situation might be modified by an actual change in acreage. But again, since the yield factor is so important, since the general trend in corn acreage is apparently directly dependent upon the American demand (supplemented to some extent by the European demand) for milk and meat, and since pork production can more easily and quickly be varied than can beef, or lamb, or dairy production, a change in corn acreage will not necessarily mean a stabilized hog production.

CAN THE DEMAND SITUATION BE FORECAST?

If hog production is to be adjusted in a rational manner to the prospective price situation both the future supply and the future demand situation must be forecast. To obtain some idea as to whether this can be done, the agricultural-outlook work of the United States Department of Agriculture is now considered.

In midwinter of each year since 1923–24, the Bureau of Agricultural Economics of the department has issued an agricultural-outlook report (7). Each report has contained a hog statement. These statements are here briefly summarized and checked. The forecasted prices and supplies in comparision with the actually realized prices and supplies for the period from 1924–25 through 1930–31 were:

1924: Indications are that hog producers have now passed the peak of production and may be moving into one of the recurrent periods of low production.

Correct: Hog prices were about $7 per hundredweight when this statement was made. They advanced steadily throughout the year as market receipts decreased, and reached $11 the next winter.

1925: Hog producers entered 1925 * * * with every indication that prices during the next 18 months will be higher than at any time since 1920.

Correct: Prices went to $14 per hundredweight at Chicago in 1926 and stayed well up until 1927.

1926: The outlook for the swine industry throughout 1926 appears very favorable, with indications that hog prices will be maintained at high levels.

Correct: Chicago prices averaged $0.50 per hundredweight higher in 1926 than in 1925, and hog production was at the low point in the cycle.

1927: The market supply of hogs will probably be little if any larger than in 1926, and domestic demand is expected to continue strong.

Incorrect: Market receipts and inspected slaughter increased, domestic demand slackened, and 1927 Chicago prices were about $2.50 per hundredweight lower than in 1926.

1928: Hog prices seem likely to show some strengthening next fall and winter when market supplies will be affected by curtailed production. Some improvement in domestic demand is anticipated but export demand during the greater part of 1928 promises to be even lower than in 1927.

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Correct: Marketings increased the next fall but decreased during the winter and, although export demand weakened, prices were higher through the last half of 1928 and into 1929.

1929: The hog outlook for 1929 is favorable. * * * The seasonal levels of hog prices in 1929 and 1930 are expected to average higher than in 1928.

Correct: Although numbers marketed increased in 1929, the price received per hundredweight was higher than in 1928 and continued into 1930 on the same level.

Information as to hog supplies for the marketing-year, November, 1928, to October, 1929, indicates an inspected slaughter of 44,000,000 to 46,000,000 head. * * * The decrease for this crop-year from that of 1927–28 is thus indicated as from 2,000,000 to 4,000,000 head.

Incorrect: The expected decrease failed to materialize. In fact, the increase about equaled the expected decrease.

1930: Hog prices in 1930 are expected to average at least as high as in 1929, and possibly higher. A reduction in slaughter supplies is indicated, but this probably will be partially offset by a decrease in foreign and domestic demand * * *.

Correct: Although Chicago hog prices for the 1929–30 hog marketing year averaged about $0.50 per hundredweight less than in 1928–29, they were not greatly changed and were strong in comparison with the general price situation. Supplies were smaller, and both foreign and domestic demand were weak.

1931: Slaughter supplies of hogs during the remainder of the present marketing year ending September 30, 1931, will probably be smaller than during the corresponding period of 1930, but with a weaker demand for hog products, prices of hogs for the period will probably average lower than for the same period of last year.

Correct: Although marketings were approximately 1,000,000 head less in the last nine months of the 1930–31 hog marketing year than in the 1929–30 year, prices averaged $3 to $4 per hundredweight lower.

The hog industry during the marketing year that begins October 1, 1931, is expected to be in a more favorable position than in the current year, since indications point to slightly smaller supplies, lower feed costs, and some improvement in both foreign and domestic demand during that period.

Incorrect: Supplies were slightly increased, and foreign and domestic demand failed to improve in the 1931–32 hog marketing year so that prices averaged lower than in the 1930–31 year.

Through the 8-year period considered, the central forecast has been more nearly correct than incorrect six times, and more nearly incorrect twice. This indicates that a good approach has been made to the problem of 6-month to 18-month forecasting. But it does not indicate that the problem has been solved. The demand situation is especially difficult to forecast. Also, the hog producer is interested in a longer time forecast than most of those quoted.

THE ADJUSTMENT PROBLEM

Since it is now understood that the year-to-year variation in corn production is, to a large extent, an uncontrollable variation; that an increase in beef-cattle or hog production may be expected to result in a more-than-proportionate decrease in price, and that, to some extent, the hog supply and price situation may be forecast, the problem as to what hog producers may do in order to adjust their hog production to the most profitable level from time to time may be considered.

So long as most hog producers continue to respond to changes in corn supplies and the corn-hog ratio as they have responded in the past, individual producers can respond in an independent manner and secure a substantial gain provided they (1) readjust their hog production and marketing program from time to time in response to the hog-price outlook instead of to an already realized price situation, and (2) consider, when planning their hog production, not only

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the hog-price outlook but also the outlook for the alternative enterprises in which they may engage, and increase their hog production only when the relative outlook is favorable.

The number of individual producers who can profit by this process is limited. The greater number of producers, unless their past responses have been economically justifiable, can not respond in the same profitable manner as can the smaller number, since a reversal of the usual mass response would necessarily result in at least a partial reversal of the expected supply-and-price situation.

The determination of a sound national hog production and marketing program is a different problem from the determination of an individual program. Any national program, to be successful, must consider the present individualistic organization of the hog-production system and the relation between the hog enterprise and the other enterprises in which the typical producer is engaged or may engage.

Some of the questions that must be considered before a national program can be successfully formulated are: Would a stable hog-production system be more profitable than the present unstable system? With what success can the variation in the general consumer-demand level be forecast? Could the corn supply be equalized from year to year at a reasonable storage cost? Can the typical individual producer be induced to change his production against his apparent self-interest in order that all producers may eventually profit?

SUMMARY

The analysis of the farmers' response to price which was outlined in the first part of this bulletin has been completed. The general conclusions that have been reached are:

The average market price for hogs varies from year to year in response to changes in hog supplies and urban buying power. But the changes in market supplies originate not in the market but on the farm.

Farmers increase or decrease their hog production and subsequent marketings from year to year in response to the corn-and-hog price situation (which is best measured by the corn-hog ratio) the same year and one year before the change in production is made.

The average weight at which hogs are marketed from year to year is largely determined by the corn supply per hog in the Corn Belt at the beginning of the hog-marketing year, by the preceding summer-period corn-hog ratio, and by the percentage concentration of United States hog numbers in the Corn Belt.

The distribution of hog marketings between the winter and summer marketing seasons is closely associated with the corn supply per hog in the Corn Belt at the beginning of the hog-marketing year and the preceding summer-period corn-hog ratio.

The short-time or day-to-day changes in hog marketing are in large part made in response to corresponding short-time market-price changes. When prices move above the prevailing seasonal level, receipts tend to follow, and when prices move down, receipts tend to slacken.

The same general type of analysis which will explain the variation in the total United States hog production will also explain the variation in hog production within an individual market district, a State, or a broad type-of-farming area.

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When the sectional changes in hog production are studied, certain differences in the type of price response made become apparent. Within the last decade, the hog-production response in the Corn Belt has been made to the corn-hog ratio. In the dairy section, the corn-hog ratio response has been modified by the skim-milk situation. On the Pacific coast, the response has been more nearly made to the barley-hog than to the corn-hog ratio. In the South, the response has been directly related to the acreage of corn, and indirectly related to the price of cotton.

The response of hog production to economic influences is apparently in no way a selective response, the producers tend to respond to innumerable weather, personal preference, disease, and economic influences, with the economic response becoming dominant only when a large number of individual cases is considered.

Although a much more exact explanation can be obtained by using the corn-hog ratio and hog prices, the year-to-year variation in hog production may be explained in large part by the supply of corn. The supply of corn, of course, is also an important determinant of the corn-hog ratio.

The most important factor associated with the year-to-year changes in the size of the United States corn crop is the yield factor. That part, then, of the variation in hog production which is directly caused by year-to-year changes in corn production can not well be controlled.

In the past, hog production has been increased or decreased from time to time in response to short-time changes in the corn supply. A short-time or cyclic increase in hog production, however, has tended to decrease the gross return to the collective mass of producers, and a decrease in production has tended to result in an increased total return.

So long as the majority of hog producers continue to respond to the corn-hog ratio and feed-supply situation in the future as in the past, the prospective hog-supply situation can be forecast, and individual producers can profit by adjusting their hog production with reference to the hog-price outlook relative to the price outlook for such alternative enterprises as may be open to them.

The purpose in making this study was not to develop a hog-production program but to enlarge the factual basis upon which an individual or an organized group may build a production program. To a certain extent, the type of material that has been presented may be used to forecast; but to expect exact forecasting is to expect too much. The direction and general degree of the coming major changes in hog production can usually be forecast, however, provided good judgment of the existing situation is used to supplement the mechanistic forecast.

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APPENDIX

In order that the analyses presented in this bulletin may be reworked and extended by those interested, the basic data involved are presented in the 14 tables that follow.

TABLE 1.—*Corn-hog ratios, farm price basis,*[1] *1910–1932*

UNITED STATES

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1910	12.2	12.0	13.6	14.4	13.3	12.9	12.2	11.7	13.0	14.2	15.1	14.9
1911	15.3	14.4	13.7	12.1	10.7	9.8	9.4	9.9	9.9	9.3	9.3	9.3
1912	9.1	8.8	8.6	9.0	8.4	8.1	8.3	9.1	10.1	12.0	13.2	14.1
1913	13.6	13.9	14.4	14.4	12.7	12.3	12.1	11.1	10.2	10.4	10.5	10.3
1914	10.8	11.3	11.2	10.9	10.3	9.9	10.1	10.3	10.2	10.0	10.4	10.2
1915	9.5	8.6	8.4	8.5	8.7	8.7	8.7	8.5	9.2	10.8	10.6	10.1
1916	9.8	10.5	11.4	11.5	11.4	11.0	10.9	10.6	11.1	10.4	10.1	9.8
1917	9.9	10.5	11.5	10.3	8.8	8.3	7.4	7.7	9.0	10.1	11.2	12.0
1918	11.2	10.3	10.1	10.2	10.3	10.0	9.9	10.1	10.8	11.0	11.5	11.3
1919	11.1	11.3	11.2	11.1	10.8	10.2	10.5	10.2	9.3	9.7	9.2	9.2
1920	9.3	9.2	8.9	8.4	7.6	7.1	7.8	8.5	10.1	13.0	15.0	13.2
1921	13.5	13.5	14.3	13.0	12.5	11.6	13.1	14.8	14.0	15.9	16.0	15.2
1922	15.4	16.5	15.8	15.7	15.0	14.7	14.7	13.7	13.4	13.4	12.8	11.7
1923	11.1	10.9	10.2	9.8	8.8	7.9	7.5	7.7	8.5	8.8	8.2	9.0
1924	9.0	8.5	8.6	8.6	8.5	8.1	6.7	8.0	7.7	8.7	8.7	7.9
1925	8.3	8.4	10.6	11.2	10.0	9.7	11.5	11.4	11.6	13.4	14.3	14.9
1926	15.8	17.2	17.5	17.5	17.8	18.7	17.7	14.7	15.8	16.2	17.3	17.0
1927	17.1	16.8	16.7	15.9	12.9	9.4	9.3	9.5	10.3	11.6	12.2	10.8
1928	10.3	9.6	8.7	8.4	8.6	8.5	9.4	10.2	11.7	11.3	11.3	10.4
1929	10.2	10.2	11.3	11.7	11.6	11.3	11.3	10.7	9.8	9.9	10.5	10.9
1930	11.4	12.2	12.8	11.7	11.6	11.5	10.9	9.5	10.3	10.7	12.4	11.5
1931	11.8	11.6	12.0	12.0	11.3	10.6	11.5	12.3	12.6	14.1	11.9	10.9
1932	11.2	10.9	12.1	11.4	------	------	------	------	------	------	------	------

CORN BELT [2]

1916	------	------	------	------	------	------	------	------	12.6	11.2	10.9	10.9
1917	11.1	12.1	13.3	11.8	10.2	9.5	8.0	8.5	9.9	10.7	12.2	13.3
1918	12.3	11.4	11.5	11.6	11.7	15.0	11.2	11.8	12.3	12.7	13.1	12.4
1919	12.3	12.9	12.8	12.5	12.0	11.5	11.6	11.2	10.0	10.4	10.8	9.6
1920	10.0	10.1	9.8	9.0	8.1	7.7	8.9	9.8	11.9	15.9	18.9	15.9
1921	16.2	17.1	19.1	16.8	16.3	14.7	17.1	19.7	17.7	20.1	19.8	17.8
1922	18.7	20.2	19.8	18.9	18.6	18.2	17.8	16.0	15.5	15.5	13.1	12.3
1923	12.4	11.9	11.3	10.6	9.3	7.9	8.3	8.7	10.2	9.2	9.0	9.7
1924	9.9	9.4	9.6	9.6	9.6	9.0	6.9	8.6	8.3	9.5	9.1	8.1
1925	8.7	9.0	12.1	12.8	11.2	10.7	12.5	12.6	13.0	15.4	16.3	17.3
1926	17.8	19.7	20.6	20.3	20.6	21.5	19.9	15.5	17.0	17.1	18.4	18.1
1927	18.4	18.3	18.5	17.3	13.4	9.5	9.4	9.6	10.8	12.3	12.8	11.0
1928	10.8	10.0	9.1	9.0	9.2	9.2	10.4	11.4	13.0	12.2	12.4	11.3
1929	11.1	11.2	12.8	13.3	13.0	12.5	12.6	11.7	10.4	10.4	11.3	11.9
1930	12.6	13.8	14.8	13.2	13.1	13.0	12.2	10.1	11.2	11.7	13.9	12.4
1931	12.9	12.9	13.8	13.8	12.9	12.0	13.2	14.0	14.1	15.9	12.3	11.2
1932	11.5	11.5	13.5	12.7	------	------	------	------	------	------	------	------

OHIO

1916	------	------	------	------	------	------	------	------	12.0	10.7	10.6	10.1
1917	10.5	11.7	12.8	11.0	9.4	8.9	8.0	8.8	9.8	10.3	11.1	12.0
1918	11.9	11.0	11.6	11.8	11.7	11.1	10.9	11.6	11.7	11.6	12.2	11.8
1919	11.3	11.9	12.3	11.8	11.2	10.6	11.0	10.8	9.7	9.9	11.0	9.8
1920	9.9	10.1	9.7	9.7	8.3	7.5	8.9	9.6	11.1	14.2	15.4	13.4
1921	14.1	14.8	16.7	14.8	14.3	12.9	15.3	16.1	13.8	16.2	16.8	15.7
1922	16.3	17.8	18.1	16.3	16.1	15.5	15.8	13.6	13.6	13.9	12.2	11.5
1923	11.4	10.8	10.3	9.8	9.0	7.5	8.1	8.4	9.7	9.3	8.7	8.9
1924	9.7	9.2	9.5	9.5	9.0	9.0	7.0	8.3	8.1	8.4	8.5	7.9
1925	8.1	8.0	10.4	11.4	9.9	9.7	11.4	11.6	12.2	14.8	18.0	18.3
1926	18.7	19.5	20.0	20.0	19.8	20.9	19.7	16.2	17.5	17.2	18.6	19.8
1927	19.3	18.7	19.3	18.5	14.1	9.4	9.7	9.9	10.1	11.5	11.8	10.8
1928	10.5	9.5	8.4	8.2	8.6	8.5	9.5	10.3	12.0	11.5	11.7	10.5
1929	10.5	10.3	11.6	12.0	11.9	11.7	11.8	11.0	9.9	9.9	10.6	11.7
1930	12.5	13.8	14.4	12.9	12.6	12.3	12.0	9.8	10.5	11.0	12.8	11.8
1931	11.6	11.5	11.7	11.4	11.0	10.3	11.9	12.9	13.3	16.1	13.4	12.9
1932	13.3	13.1	14.8	13.9	------	------	------	------	------	------	------	------

Compiled from records of the Division of Crop and Livestock Estimates.

[1] Number of bushels of corn required to buy 100 pounds of live hogs at farm prices, as reported monthly in Crops and Markets.

[2] Ohio, Indiana, Minnesota, Illinois, Wisconsin, Iowa, Missouri, South Dakota, Nebraska, and Kansas. The State weights used in calculating these ratios are given in Table 2.

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TABLE 1.—*Corn-hog ratios, farm price basis, 1910–1932*—Continued

INDIANA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1916	------	------	------	------	------	------	------	------	12.7	11.7	11.4	11.0
1917	11.2	12.3	13.4	11.7	9.9	9.3	8.1	8.8	10.1	10.6	11.9	12.8
1918	12.4	12.0	12.5	12.4	12.1	11.3	11.5	12.4	12.9	12.9	13.7	12.9
1919	12.8	13.2	13.1	12.6	12.0	11.1	11.3	11.0	9.7	10.1	10.9	9.6
1920	9.8	9.9	9.6	9.2	7.8	7.5	8.9	9.8	11.8	15.6	17.6	14.7
1921	15.6	16.2	18.5	15.4	15.3	14.2	16.6	17.6	15.9	18.1	16.9	17.4
1922	18.5	19.6	19.6	18.1	18.1	17.7	17.4	15.3	15.0	15.7	14.2	12.8
1923	12.1	11.6	11.0	10.3	9.2	8.0	8.4	8.8	10.4	9.9	10.0	10.0
1924	10.6	10.3	9.9	10.1	10.3	9.4	7.3	9.0	8.6	9.6	9.4	8.2
1925	9.0	9.0	11.6	12.6	11.4	10.7	12.9	13.0	13.0	15.5	19.0	20.2
1926	19.8	21.7	22.1	22.2	22.9	23.8	22.5	17.8	20.0	19.2	21.4	22.2
1927	22.7	21.3	21.5	20.2	15.7	10.0	10.1	10.3	11.2	12.5	12.8	11.7
1928	11.1	10.3	9.0	8.5	9.0	9.0	10.1	11.1	12.8	12.8	13.0	10.9
1929	11.0	10.9	12.4	12.7	13.0	12.2	12.6	11.3	10.0	10.1	11.6	12.2
1930	12.9	14.3	15.1	13.6	13.2	13.1	12.5	10.6	11.4	12.1	14.1	12.8
1931	13.3	13.2	13.8	13.3	12.8	12.2	13.9	14.8	15.4	20.0	15.7	15.0
1932	16.0	15.8	17.9	17.0	------	------	------	------	------	------	------	------

ILLINOIS

1916	------	------	------	------	------	------	------	------	12.5	11.1	10.8	10.8
1917	11.1	11.9	13.2	11.6	9.9	9.3	7.9	8.3	9.6	10.6	12.5	14.3
1918	13.0	11.8	12.3	12.4	12.9	12.5	11.9	12.4	12.9	13.4	13.7	12.8
1919	12.8	13.4	12.9	12.3	11.8	11.2	11.3	11.0	9.9	10.3	10.6	9.1
1920	9.6	9.7	9.4	8.6	7.7	7.4	8.6	9.6	11.4	15.3	17.2	14.3
1921	14.8	15.7	17.2	15.6	14.1	13.3	15.4	17.5	17.6	18.5	18.1	16.6
1922	17.5	18.9	19.4	18.2	17.4	17.4	17.1	15.7	15.7	15.4	13.3	12.3
1923	12.2	11.7	11.2	10.6	9.3	7.9	8.4	9.0	10.2	9.5	9.3	9.4
1924	9.9	9.6	9.7	9.6	9.4	8.8	6.9	8.6	8.1	9.5	9.3	8.0
1925	8.8	9.2	12.1	12.1	10.8	10.4	12.4	12.9	13.4	16.0	16.0	17.5
1926	18.1	19.2	21.0	20.3	21.0	21.6	21.1	16.6	18.0	17.8	19.8	18.8
1927	20.2	19.7	20.6	19.1	14.7	9.8	9.7	9.9	10.9	12.4	12.6	10.8
1928	10.8	10.0	9.2	8.9	9.1	9.1	10.4	11.2	12.7	12.4	12.5	11.4
1929	10.8	11.0	12.6	12.6	12.7	12.2	12.1	11.7	10.4	10.4	11.3	11.9
1930	12.5	13.9	14.9	13.3	13.1	13.1	12.4	10.2	11.1	11.8	13.8	12.1
1931	12.5	12.7	13.6	13.7	12.9	12.0	13.5	14.6	15.6	18.1	14.7	13.7
1932	14.1	13.8	16.8	15.4	------	------	------	------	------	------	------	------

MINNESOTA

1916	------	------	------	------	------	------	------	------	12.5	11.5	11.2	11.0
1917	11.3	12.3	13.3	12.2	10.7	9.9	8.4	8.8	10.2	10.6	12.1	13.9
1918	12.8	11.9	11.6	11.6	11.9	11.8	11.4	12.5	13.2	13.6	14.6	13.9
1919	14.1	14.5	14.4	14.0	13.4	12.8	12.8	12.2	11.1	11.4	11.3	10.6
1920	10.9	10.8	10.5	9.4	8.8	8.4	9.5	10.5	12.3	15.9	19.3	18.0
1921	17.5	18.0	20.5	18.3	17.7	15.1	16.4	19.3	17.1	19.4	20.3	18.8
1922	19.1	21.5	21.1	19.8	19.6	19.4	18.2	16.2	15.7	16.0	13.7	13.2
1923	13.4	13.0	12.4	11.6	10.1	8.8	8.7	9.3	10.9	9.6	9.4	9.8
1924	10.5	9.8	10.2	10.0	10.5	9.4	7.2	8.8	8.1	9.1	9.3	8.8
1925	9.6	10.1	14.4	14.9	12.9	11.6	12.9	12.8	13.4	16.9	17.0	18.9
1926	19.3	21.3	22.1	21.7	21.9	22.5	19.5	15.2	17.1	17.7	20.4	19.3
1927	18.8	18.6	19.5	18.7	14.3	10.1	9.8	9.6	11.1	13.2	13.0	11.5
1928	11.0	10.7	9.7	9.7	9.7	9.8	10.4	12.0	14.1	14.2	13.5	12.4
1929	11.9	12.1	13.6	14.4	14.4	13.8	13.2	12.6	11.1	11.1	12.7	12.7
1930	13.3	14.5	16.2	14.4	14.3	14.6	13.4	10.2	11.8	12.8	15.5	13.8
1931	14.3	14.6	15.6	15.1	14.4	13.5	13.5	14.4	13.4	15.4	11.1	9.4
1932	9.2	9.4	11.2	9.7	------	------	------	------	------	------	------	------

WISCONSIN

1916	------	------	------	------	------	------	------	------	12.0	10.5	9.7	9.6
1917	10.1	10.8	12.4	11.9	10.4	9.5	8.9	8.8	9.3	9.4	8.9	9.8
1918	9.7	9.4	9.2	9.6	9.6	9.9	10.1	11.0	11.9	12.7	12.6	12.4
1919	12.5	13.0	13.5	13.3	12.6	12.0	12.1	11.6	10.4	10.5	10.2	9.5
1920	10.0	9.7	9.4	8.8	8.2	7.3	8.0	8.9	9.8	12.5	14.0	10.7
1921	11.7	12.2	13.8	12.6	11.9	10.9	12.5	14.3	12.9	14.0	14.3	13.5
1922	14.0	15.8	16.1	15.3	15.3	14.8	13.8	13.3	13.8	14.1	12.1	11.1
1923	11.3	11.3	10.6	10.0	9.3	7.8	7.7	7.9	9.4	8.3	7.3	7.7
1924	8.2	8.2	8.1	8.2	8.0	7.6	6.6	7.5	7.8	8.3	7.4	7.1
1925	8.0	7.9	10.0	11.1	9.6	9.4	10.6	10.9	11.6	12.9	14.2	13.8
1926	14.7	16.2	16.5	16.7	17.0	17.6	16.4	13.9	15.2	15.5	15.2	14.3
1927	14.4	14.4	14.3	14.2	11.8	8.8	8.6	8.6	9.0	10.7	10.4	9.2
1928	9.0	8.7	8.0	8.0	8.2	8.5	9.3	10.0	12.1	10.8	10.4	10.3
1929	10.0	10.3	11.3	11.7	11.7	11.6	11.8	10.7	10.1	9.9	10.1	10.1
1930	10.7	11.6	12.4	11.6	11.4	11.5	10.9	9.6	10.6	10.7	11.4	10.6
1931	10.6	10.6	11.0	10.8	10.2	9.5	10.3	10.7	10.6	10.5	8.4	8.0
1932	7.8	7.7	9.3	8.1	------	------	------	------	------	------	------	------

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TABLE 1.—*Corn-hog ratios, farm price basis, 1910–1932*—Continued

IOWA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1916	------	------	------	------	------	------	------	------	13.0	11.7	11.5	11.4
1917	11.7	12.7	13.5	12.1	10.6	9.8	8.1	8.5	10.1	11.0	13.0	14.2
1918	12.9	12.0	12.0	11.9	12.0	11.6	11.5	12.2	12.8	13.5	13.9	12.7
1919	12.6	13.3	13.3	12.7	12.3	11.8	11.9	11.4	10.3	11.0	11.6	10.1
1920	10.7	10.8	10.4	9.3	8.4	8.0	9.3	10.3	12.7	17.2	20.9	16.9
1921	16.9	18.3	20.0	18.3	17.6	15.9	18.4	21.7	18.2	21.6	21.8	19.4
1922	20.0	21.5	21.1	20.4	20.0	19.2	19.0	17.2	15.8	15.8	13.7	12.8
1923	13.3	12.5	11.9	11.2	10.0	8.3	8.6	8.9	10.4	9.2	8.9	10.2
1924	10.2	9.5	9.8	10.0	10.0	9.4	6.9	8.5	8.3	9.9	8.9	8.0
1925	8.8	8.9	12.2	13.4	11.4	10.8	12.6	12.6	13.1	15.6	16.9	17.9
1926	18.0	20.7	21.7	21.5	21.4	22.8	20.5	15.3	17.0	17.8	19.1	18.9
1927	18.8	19.2	19.1	17.6	13.3	9.4	9.3	9.4	10.7	12.2	12.8	10.5
1928	10.6	9.7	9.0	9.2	9.2	9.3	10.5	11.5	13.0	12.2	12.6	12.0
1929	11.4	11.5	13.6	14.2	13.6	13.0	13.1	11.9	10.4	10.6	11.8	12.3
1930	12.8	14.1	15.3	13.3	13.4	13.2	12.1	10.1	11.3	11.9	14.5	12.4
1931	12.7	12.5	13.6	14.2	13.0	12.0	12.8	13.7	14.1	15.7	11.7	10.6
1932	10.6	11.0	13.1	12.6	------	------	------	------	------	------	------	------

MISSOURI

1916	------	------	------	------	------	------	------	------	11.3	10.1	9.9	9.9
1917	9.7	10.7	12.3	10.8	9.1	8.6	7.4	8.0	9.8	11.6	13.1	12.8
1918	11.5	10.3	10.5	10.8	11.0	10.6	10.4	10.5	10.6	10.6	11.0	10.8
1919	10.7	10.6	10.9	11.3	10.8	10.3	10.2	10.2	8.9	9.1	9.6	8.5
1920	8.7	8.9	8.6	8.1	7.2	6.7	7.5	8.3	10.2	13.7	15.8	13.0
1921	13.2	13.8	15.5	12.2	12.4	11.9	14.1	15.9	14.8	17.6	16.8	14.8
1922	15.5	17.0	16.5	14.8	15.0	14.5	14.1	13.9	13.2	14.4	11.4	10.6
1923	10.3	10.1	9.9	9.0	7.7	6.7	7.1	7.4	8.7	7.8	7.6	7.7
1924	7.8	7.6	7.7	7.6	7.6	7.1	6.2	7.7	7.5	8.9	8.7	7.8
1925	8.3	8.3	10.7	10.6	10.3	9.8	11.7	11.5	12.0	13.8	14.7	15.2
1926	15.9	16.9	17.6	17.7	17.7	18.5	17.7	14.1	15.5	15.4	16.3	16.4
1927	16.4	16.4	15.9	15.4	12.1	8.9	8.8	9.3	10.0	10.8	11.4	10.4
1928	9.7	9.3	8.3	8.0	8.3	8.2	9.3	10.1	11.5	11.0	11.8	10.1
1929	10.5	10.4	10.7	11.4	11.4	11.2	11.3	10.4	9.4	9.4	9.4	9.5
1930	10.6	11.2	11.6	10.8	11.1	11.1	10.0	9.2	9.9	10.1	10.7	10.3
1931	10.7	10.8	11.3	11.0	10.3	9.5	11.1	11.6	12.4	13.5	11.9	11.2
1932	11.6	10.6	12.3	11.7	------	------	------	------	------	------	------	------

SOUTH DAKOTA

1916	------	------	------	------	------	------	------	------	13.3	11.8	11.4	11.6
1917	11.6	12.3	14.2	12.4	10.7	10.0	8.5	9.0	10.5	12.0	12.8	13.4
1918	12.8	11.7	11.8	11.7	11.9	11.8	12.0	12.6	12.9	13.0	14.0	13.8
1919	13.3	14.3	14.4	13.8	12.7	12.3	12.6	11.9	10.7	11.3	11.0	9.7
1920	10.3	10.6	9.0	8.9	8.3	7.9	8.9	10.1	12.7	17.2	22.0	19.3
1921	19.5	21.9	24.2	22.6	20.3	18.1	20.6	24.7	23.1	27.0	26.8	22.0
1922	23.7	21.9	22.4	22.2	21.7	21.9	21.2	18.3	18.2	17.5	14.5	14.2
1923	14.5	13.8	13.1	12.2	10.2	8.6	8.9	9.4	10.9	10.0	10.3	11.4
1924	11.3	10.3	10.3	10.7	10.9	10.2	7.1	8.9	8.1	9.4	9.4	8.9
1925	9.6	10.6	13.9	15.3	13.1	11.8	13.9	13.9	13.2	16.6	15.8	16.4
1926	16.8	19.7	20.0	19.8	21.5	20.6	17.9	14.4	16.9	17.0	19.1	17.7
1927	18.3	17.7	17.5	16.1	13.3	9.6	9.5	9.5	11.1	13.8	14.3	12.4
1928	12.3	11.4	10.3	10.4	10.4	10.2	11.4	12.7	14.4	13.1	13.1	11.7
1929	11.8	11.7	13.2	14.1	13.9	13.7	13.2	12.3	11.0	11.3	12.5	13.0
1930	13.5	15.2	16.5	14.8	14.5	14.6	13.4	10.7	12.1	12.8	16.7	14.8
1931	15.0	14.9	16.5	15.9	15.0	13.8	14.1	13.7	12.0	12.8	9.5	8.0
1932	8.4	8.1	9.7	8.6	------	------	------	------	------	------	------	------

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TABLE 1.—*Corn-hog ratios, farm price basis, 1910–1932*—Continued

NEBRASKA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1916	------	------	------	------	------	------	------	------	13.2	11.6	11.4	11.5
1917	12.0	12.9	14.3	12.3	10.5	9.8	8.0	8.6	10.1	10.5	11.8	13.3
1918	12.3	11.3	11.3	11.7	11.5	11.0	11.0	11.6	12.1	12.6	12.8	12.0
1919	12.2	12.8	12.7	12.7	12.2	11.8	11.9	11.4	9.7	10.3	10.8	9.8
1920	10.4	10.5	10.2	9.0	8.2	8.0	9.4	10.6	13.1	18.5	22.0	19.0
1921	20.0	20.8	22.9	19.4	20.3	17.4	20.8	24.1	21.0	23.8	22.8	19.6
1922	21.7	23.3	21.7	22.0	21.2	20.9	20.0	17.1	17.0	15.6	12.7	12.1
1923	12.8	12.4	11.7	10.6	8.9	7.4	8.3	9.0	10.9	9.6	9.7	11.2
1924	10.9	10.0	10.5	10.3	10.3	9.4	7.2	8.9	8.8	9.9	9.5	8.1
1925	8.5	9.0	12.1	13.4	11.2	11.0	13.0	13.2	13.1	15.6	15.1	16.1
1926	17.3	20.3	20.9	20.0	20.2	21.5	19.7	14.9	15.9	15.9	15.7	15.3
1927	16.0	16.5	16.6	15.5	12.1	9.4	9.4	9.8	11.3	13.2	13.9	11.8
1928	11.6	10.6	9.6	9.5	9.8	9.8	11.1	12.4	13.9	11.8	11.5	10.3
1929	11.0	11.4	13.1	13.7	13.2	12.6	12.8	12.0	10.6	10.7	11.6	12.2
1930	13.0	14.5	15.8	13.8	13.8	13.6	12.7	10.8	11.8	12.3	15.2	13.6
1931	14.7	15.0	16.1	16.1	14.8	13.9	14.8	15.5	14.3	14.8	10.5	9.2
1932	9.4	9.4	11.3	11.4	------	------	------	------	------	------	------	------

KANSAS

1916	------	------	------	------	------	------	------	------	12.4	10.6	10.0	10.1
1917	10.4	11.4	12.8	11.1	9.9	9.3	7.9	8.2	9.6	10.5	11.5	12.2
1918	10.9	9.9	9.8	10.1	10.3	10.1	10.3	10.5	10.9	10.4	10.8	10.6
1919	10.5	11.0	11.2	11.4	11.1	10.7	10.9	10.6	9.4	9.4	9.4	8.7
1920	9.0	9.2	9.2	8.6	7.8	7.4	8.4	9.3	11.2	14.9	20.0	16.7
1921	16.7	16.5	19.3	17.0	16.1	14.9	17.8	21.5	20.3	21.6	20.0	17.6
1922	17.8	20.0	18.8	18.0	18.6	18.1	17.9	17.0	16.5	15.8	12.4	11.6
1923	11.4	11.2	10.6	9.6	8.4	7.5	7.9	8.0	10.0	8.8	8.6	8.9
1924	9.2	8.7	9.1	8.9	8.9	8.4	6.9	9.0	8.9	10.1	10.0	8.5
1925	8.7	9.2	12.8	12.8	11.4	11.2	13.4	13.4	13.5	15.0	14.9	15.5
1926	17.0	18.6	19.3	19.3	19.0	20.6	19.4	14.8	15.7	15.5	15.5	15.3
1927	15.4	15.7	15.7	14.7	11.9	8.7	9.0	9.6	11.3	12.8	14.4	12.0
1928	11.7	10.7	9.6	9.4	9.8	9.9	11.4	12.5	14.2	12.5	12.8	11.7
1929	11.6	12.0	13.3	14.0	13.6	12.9	13.1	12.0	10.6	10.3	10.8	11.7
1930	12.6	13.4	14.3	12.8	12.5	12.3	11.9	10.2	11.2	11.4	13.1	12.4
1931	13.7	13.2	14.0	13.9	12.7	12.2	14.4	15.4	15.1	16.4	12.8	11.0
1932	11.7	11.8	12.9	11.9	------	------	------	------	------	------	------	------

TABLE 2.—*State weights used in calculating the Corn Belt and the three market area corn-hog ratios on a farm-price basis*

State	Corn Belt	East St. Louis	St. Joseph	Kansas City
Ohio	1.00	------	------	------
Indiana	1.00	------	------	------
Illinois	2.00	3.50	------	------
Minnesota	1.00	------	------	------
Wisconsin	.50	------	------	------
Iowa	3.00	1.00	1.50	.25
Missouri	1.00	4.75	4.50	3.25
South Dakota	.50	------	------	.25
Nebraska	1.50	.25	2.75	1.50
Kansas	1.00	.50	1.25	4.75

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TABLE 3.—*Corn-hog ratios, Chicago price basis,*[1] *1904–1932*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
1904	11.4	11.2	11.6	10.4	9.5	10.1	11.0	10.2	10.8	9.8	10.0	10.5
1905	11.1	11.0	10.9	11.4	10.8	9.7	9.9	11.0	10.4	9.9	10.8	11.7
1906	12.9	14.3	15.8	15.6	13.7	13.4	12.8	11.6	13.3	13.9	14.4	14.9
1907	16.1	16.4	15.5	15.1	12.3	11.5	11.2	10.5	9.4	9.5	8.3	8.1
1908	8.3	8.2	7.9	9.0	7.5	8.1	8.6	8.1	8.6	7.7	9.2	9.6
1909	9.5	9.8	10.2	10.4	10.0	10.2	10.9	11.1	11.9	13.1	13.6	14.2
1910	13.4	14.4	17.3	17.4	15.9	16.0	14.1	13.0	15.3	17.0	15.5	17.0
1911	17.7	16.4	15.2	12.5	11.1	11.4	10.6	11.2	10.3	8.8	9.3	10.5
1912	10.1	9.7	10.4	10.0	9.7	10.0	11.2	10.4	11.4	13.5	14.9	16.1
1913	16.2	17.0	18.2	16.5	15.0	14.4	14.6	11.3	11.1	11.7	10.8	11.7
1914	13.4	13.9	13.6	12.9	12.1	11.4	12.3	11.0	11.2	10.5	11.2	11.1
1915	9.7	9.2	9.4	9.7	9.9	10.3	9.3	8.5	9.8	12.2	10.6	9.3
1916	9.7	11.1	13.2	12.8	13.1	13.1	12.1	12.1	12.4	10.2	9.8	10.8
1917	11.1	12.4	13.6	11.2	10.0	9.1	7.6	8.2	8.7	8.4	7.9	9.5
1918	9.2	9.2	10.1	10.6	10.9	10.2	10.4	11.0	12.4	12.6	13.3	12.1
1919	12.3	13.9	12.5	12.6	11.8	11.5	11.4	10.3	11.3	10.2	9.7	9.3
1920	9.9	10.0	9.5	8.8	7.1	7.8	9.4	9.3	12.1	15.6	15.4	12.9
1921	14.5	15.0	16.1	14.9	13.9	13.0	16.2	16.5	14.4	17.2	14.9	14.7
1922	16.7	18.0	18.3	17.8	16.9	16.9	15.2	13.7	13.7	12.8	11.4	11.2
1923	11.8	11.1	11.2	10.2	9.2	8.2	8.0	8.7	9.4	7.1	8.4	9.7
1924	9.3	9.1	9.5	9.6	9.5	8.6	7.0	8.0	8.4	9.0	8.1	7.8
1925	8.4	9.1	11.6	12.0	10.5	11.1	12.5	12.4	13.8	13.8	13.6	14.4
1926	15.2	16.6	16.9	17.4	19.1	20.0	16.0	14.4	15.2	16.5	16.6	15.4
1927	16.2	16.1	16.6	15.1	11.0	8.9	8.9	8.3	10.5	12.4	10.6	9.7
1928	9.3	8.5	8.2	8.8	9.0	9.6	10.0	11.3	11.9	10.0	10.5	10.4
1929	9.9	10.8	12.2	12.7	12.4	11.8	11.3	10.4	9.8	9.9	10.3	10.6
1930	11.5	13.0	12.7	12.2	12.7	12.1	10.6	9.7	10.4	11.4	12.0	11.5
1931	11.8	11.6	12.4	12.5	11.7	11.0	11.1	13.0	12.9	13.4	10.7	11.4
1932	10.8	11.4	13.1	12.0	------	------	------	------	------	------	------	------

Bureau of Agricultural Economics.

[1] These ratios represent the number of bushels of corn required to buy 100 pounds of live hogs and are based upon the average monthly price of hogs and of No. 3 Yellow corn, both at Chicago.

TABLE 4.—*Hogs: Average price per 100 pounds at Chicago, 1904–1932* [1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Dolls.	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
1904	4.90	5.15	5.35	5.10	4.65	5.05	5.40	5.30	5.75	5.40	4.80	4.50
1905	4.65	4.85	5.15	5.45	5.40	5.35	5.65	5.95	5.50	5.25	4.85	4.90
1906	5.40	6.00	6.30	6.55	6.45	6.55	6.65	6.25	6.25	6.40	6.20	6.25
1907	6.60	7.05	6.65	6.65	6.40	6.10	6.05	6.00	6.00	6.15	4.90	4.70
1908	4.40	4.45	5.00	5.85	5.50	5.80	6.50	6.55	6.85	5.95	5.80	5.65
1909	6.10	6.35	6.70	7.20	7.30	7.65	7.85	7.75	8.20	7.75	8.00	8.35
1910	8.55	9.05	10.55	9.90	9.55	9.45	8.75	8.35	8.90	8.50	7.60	7.65
1911	7.95	7.40	6.85	6.25	6.00	6.25	6.70	7.30	6.90	6.45	6.30	6.40
1912	6.25	6.20	7.10	7.80	7.65	7.50	7.65	8.25	8.45	8.75	7.75	7.40
1913	7.45	8.15	8.90	9.05	8.55	8.65	9.05	8.35	8.30	8.20	7.75	7.70
1914	8.30	8.60	8.70	8.65	8.45	8.20	8.70	9.00	8.85	7.65	7.50	7.10
1915	6.90	6.80	6.75	7.30	7.60	7.60	7.25	6.90	7.25	7.90	6.65	6.40
1916	7.20	8.20	9.65	9.75	9.85	9.70	9.80	10.30	10.70	9.80	9.60	9.95
1917	10.90	12.45	14.80	15.75	15.90	15.50	15.20	16.90	18.20	17.15	17.40	16.85
1918	16.30	16.65	17.10	17.45	17.45	16.60	17.75	19.00	19.65	17.70	17.70	17.55
1919	17.60	17.65	19.10	20.40	20.60	20.40	21.85	20.00	17.45	14.35	14.20	13.60
1920	14.97	14.55	14.94	14.79	14.28	14.68	14.84	14.74	15.88	14.17	11.83	9.55
1921	9.41	9.42	10.00	8.50	8.35	8.19	9.69	9.26	7.61	7.72	7.01	6.92
1922	8.02	9.90	10.43	10.31	10.48	10.33	9.70	8.51	8.75	8.80	8.07	8.18
1923	8.29	8.02	8.18	8.08	7.53	6.92	7.04	7.65	8.35	7.42	6.85	6.87
1924	7.10	7.06	7.35	7.36	7.34	7.04	7.68	9.38	9.57	9.91	8.97	9.38
1925	10.38	11.06	13.55	12.55	12.06	12.57	13.46	12.66	12.52	11.31	11.28	10.97
1926	12.02	12.45	12.20	12.33	13.55	14.01	12.51	11.48	12.03	12.72	11.80	11.57
1927	11.96	11.73	11.28	10.69	9.59	8.78	9.05	9.03	10.22	10.39	8.92	8.32
1928	8.25	8.08	8.08	9.28	9.67	9.91	10.65	11.53	11.89	9.57	8.83	8.61
1929	9.22	10.19	11.44	11.41	10.81	10.72	11.20	10.52	9.85	9.38	9.06	9.34
1930	9.78	10.67	10.17	10.00	10.02	9.52	8.73	9.58	9.76	9.34	8.55	7.92
1931	7.65	7.06	7.46	7.26	6.53	6.36	6.33	5.98	5.41	5.09	4.61	4.20
1932	4.00	3.89	4.33	3.85	------	------	------	------	------	------	------	------

Division of Livestock, Meats, and Wool.

[1] Figures prior to 1920 are general average hog prices as published in the Chicago Drovers Journal Yearbook; subsequent figures compiled from reports of packer and shipper purchases—such purchases do not include pigs, boars, stags, extremely rough sows, or cripples.

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TABLE 5.—*Hogs: Slaughter under Federal inspection, 1907–1932*

[In thousands; 000 omitted]

TOTAL NUMBER INSPECTED

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1907	3,410	2,921	2,665	2,667	3,317	3,241	2,929	2,301	1,988	2,219	2,135	3,094
1908	4,961	3,890	3,111	2,304	3,088	3,094	2,416	2,231	2,231	3,368	3,803	4,147
1909	3,876	2,653	3,013	2,343	2,629	2,719	2,097	1,822	1,955	2,397	2,800	3,090
1910	2,693	2,324	1,891	1,778	2,206	2,612	1,988	1,824	1,564	1,851	2,456	2,827
1911	2,742	2,633	2,973	2,589	3,008	3,462	2,560	2,032	2,172	2,720	3,639	3,603
1912	4,147	3,302	2,700	2,412	2,844	2,835	2,354	1,875	1,701	2,455	3,020	3,407
1913	3,708	2,844	2,334	2,487	3,046	3,057	2,557	2,268	2,133	2,681	3,165	3,919
1914	3,489	2,723	2,548	2,312	2,569	2,926	2,260	1,799	1,907	2,682	3,047	4,271
1915	4,274	3,885	3,446	2,563	2,869	3,246	2,493	2,041	1,890	2,494	3,739	5,442
1916	5,387	4,276	3,430	2,853	3,275	3,163	2,530	2,517	2,287	3,327	4,771	5,267
1917	4,629	3,484	2,985	2,645	3,084	2,685	2,411	1,705	1,322	2,195	3,043	3,723
1918	3,961	3,998	3,926	3,290	3,092	2,783	2,940	2,283	1,980	3,018	4,280	5,662
1919	5,846	4,266	3,443	3,208	3,743	3,728	2,884	1,949	1,997	2,686	3,270	4,790
1920	5,079	3,104	3,482	2,590	3,585	3,566	2,644	2,191	1,988	2,487	3,329	3,985
1921	4,347	3,799	3,047	3,003	3,274	3,618	2,821	2,530	2,422	2,866	3,447	3,807
1922	3,985	3,480	3,350	2,946	3,716	4,046	3,104	2,888	2,747	3,332	4,318	5,201
1923	5,134	4,231	4,838	4,179	4,325	4,303	3,983	3,556	3,212	4,328	5,341	5,904
1924	5,911	5,006	4,536	4,073	4,278	4,288	4,114	3,070	2,857	3,498	4,641	6,600
1925	5,979	4,447	3,299	3,037	3,186	3,732	2,819	2,452	2,598	3,314	3,646	4,535
1926	4,501	3,351	3,562	3,105	3,131	3,430	3,127	2,834	2,616	2,976	3,610	4,394
1927	4,514	3,395	3,837	3,330	3,766	4,253	3,431	3,050	2,534	2,969	3,688	4,869
1928	5,479	5,780	5,140	3,446	3,885	4,078	2,984	2,545	2,508	3,713	4,455	5,782
1929	5,738	4,478	3,645	3,761	3,798	3,756	3,597	3,130	3,104	3,857	4,499	5,083
1930	5,001	4,034	3,392	3,480	3,823	3,689	3,187	2,724	2,773	3,492	4,024	4,647
1931	5,362	4,142	3,523	3,488	3,408	3,251	2,767	2,500	2,955	3,772	4,218	5,387
1932	5,027	4,590	3,664	3,714	3,940	3,320	2,802	2,970	3,252	-------	-------	-------
NUMBER PASSED FOR FOOD												
1919	5,831	4,254	3,432	3,197	3,731	3,717	2,874	1,942	1,990	2,677	3,261	4,776
1920	5,064	3,093	3,469	2,580	3,571	3,553	2,634	2,183	1,971	2,478	3,318	3,974
1921	4,335	3,787	3,037	2,993	3,263	3,606	2,810	2,520	2,412	2,852	3,433	3,792
1922	3,970	3,466	3,336	2,934	3,701	4,029	3,089	2,874	2,736	3,319	4,303	5,181
1923	5,115	4,213	4,818	4,163	4,307	4,285	3,967	3,538	3,195	4,307	5,318	5,879
1924	5,888	4,986	4,518	4,057	4,260	4,271	4,097	3,057	2,845	3,485	4,625	6,580
1925	5,959	4,431	3,286	3,024	3,173	3,716	2,808	2,442	2,587	3,303	3,635	4,519
1926	4,487	3,340	3,549	3,094	3,119	4,417	3,115	2,820	2,601	2,955	3,593	4,378
1927	4,499	3,383	3,824	3,318	3,753	4,239	3,419	3,038	2,524	2,957	3,676	4,853
1928	5,463	5,764	5,125	3,435	3,872	4,067	2,976	2,536	2,498	3,700	4,443	5,768
1929	5,724	4,466	3,635	3,750	3,786	3,744	3,585	3,117	3,093	3,847	4,487	5,069
1930	4,989	4,023	3,382	3,470	3,812	3,678	3,178	2,713	2,764	3,482	4,015	4,636
1931	5,347	4,131	3,513	3,478	3,398	3,242	2,758	2,491	2,944	3,758	4,205	5,372
1932	5,013	4,577	3,653	3,703	-------	-------	-------	-------	-------	-------	-------	-------

Bureau of Animal Industry.

TABLE 6.—*Production of pork under Federal inspection, 1919–1932*

[In million pounds; 000,000 omitted]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1919	983	724	576	537	632	642	510	349	350	445	538	783
1920	861	521	598	455	621	619	468	386	335	405	542	662
1921	748	668	530	520	559	617	528	450	420	478	565	640
1922	690	592	567	507	642	718	566	523	486	550	699	878
1923	904	749	853	735	736	749	703	641	552	711	873	976
1924	977	844	766	691	721	737	732	549	493	560	723	1,027
1925	951	723	548	519	556	650	512	457	461	564	607	774
1926	803	605	650	572	569	647	616	564	476	480	569	723
1927	784	608	695	603	682	778	653	581	459	497	597	794
1928	935	1,018	890	585	673	705	538	467	434	624	741	969
1929	974	770	636	655	666	673	676	586	552	652	738	851
1930	874	705	590	603	665	664	603	500	472	576	666	798
1931	962	732	631	624	604	597	533	457	503	611	678	899
1932	860	787	629	644	-------	-------	-------	-------	-------	-------	-------	-------

Bureau of Animal Industry.

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TABLE 7.—*Index numbers of industrial pay rolls,*[1] *1919–1932*

[1923–1925=100]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1919	97	91	92	91	91	93	96	101	106	101	105	113
1920	117	116	124	122	123	125	120	123	121	117	108	100
1921	84	82	82	80	78	76	72	74	74	73	72	74
1922	70	73	75	74	77	80	78	82	86	89	93	96
1923	94	98	103	104	107	108	103	104	105	107	105	103
1924	98	104	104	101	97	92	85	89	92	95	94	98
1925	95	101	103	100	101	99	97	100	99	105	105	106
1926	101	106	107	105	104	104	99	104	105	108	105	104
1927	99	105	106	105	104	102	99	102	102	103	98	99
1928	96	101	103	100	101	101	98	103	104	107	104	104
1929	101	108	111	111	111	110	106	111	112	111	103	99
1930	94	98	98	97	94	91	83	82	83	81	75	74
1931	68	73	75	74	72	68	64	64	62	59	56	56
1932	52	54	52	50	------	------	------	------	------	------	------	------

Federal Reserve Board.

[1] Unadjusted for trend and seasonal, as published monthly in the Federal Reserve Bulletin.

TABLE 8.—*Hogs: Marketings*[1] *from individual States, 1920–1931*

[In thousands; 000 omitted]

OHIO

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	239	122	130	107	156	166	133	111	117	140	172	199
1921	223	147	126	153	160	202	131	130	178	189	195	187
1922	173	153	208	201	234	217	151	199	223	274	337	316
1923	216	161	236	220	235	228	174	144	167	295	383	405
1924	295	174	199	226	216	214	184	122	198	271	307	340
1925	259	153	141	143	130	132	93	115	153	226	207	176
1926	178	106	144	162	154	151	133	131	192	224	136	132
1927	149	97	129	144	178	199	163	131	150	178	202	243
1928	226	179	149	144	140	142	108	86	108	227	268	262
1929	211	113	125	154	140	137	127	134	162	184	208	191
1930	154	83	108	119	131	129	104	103	137	173	177	173
1931	128	89	109	122	111	102	66	90	123	153	110	124

INDIANA

1920	437	227	208	183	294	312	257	252	231	249	355	420
1921	469	275	202	304	322	381	283	283	337	355	343	291
1922	247	195	224	257	281	304	250	294	298	384	424	446
1923	332	265	290	309	359	337	331	295	282	391	509	592
1924	481	317	246	299	289	340	320	263	278	292	407	494
1925	416	250	176	215	203	230	203	214	204	270	276	290
1926	230	178	155	175	166	218	229	210	256	266	213	192
1927	208	151	145	179	246	306	244	237	211	214	278	359
1928	347	289	202	202	223	256	208	185	192	300	400	429
1929	311	179	173	226	225	234	222	239	254	278	323	323
1930	242	145	164	198	218	246	194	184	221	272	287	296
1931	226	168	185	249	230	210	155	176	253	348	241	269

ILLINOIS

1920	693	397	420	281	432	390	321	286	259	257	454	585
1921	662	519	352	357	373	433	319	285	295	359	462	479
1922	501	370	313	285	383	438	307	321	276	345	488	617
1923	655	540	520	417	511	519	498	427	360	505	555	642
1924	828	710	477	473	474	521	507	353	321	338	472	729
1925	770	548	351	362	374	422	325	297	301	326	376	526
1926	520	411	390	358	344	391	335	346	340	344	366	401
1927	507	391	431	325	439	483	371	400	320	296	356	478
1928	775	667	533	405	432	423	351	294	246	402	471	605
1929	732	516	345	419	385	420	401	332	334	397	455	511
1930	628	418	346	398	406	407	367	325	316	388	450	542
1931	597	454	400	430	390	395	293	296	342	454	412	527

Division of Crop and Livestock Estimates.

[1] Special data compiled by the Division of Crop and Livestock Estimates from market and packer receipts data. Subject to revision.

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TABLE 8.—*Hogs: Marketings from individual States, 1920–1931*—Continued

MINNESOTA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	349	273	251	186	252	233	151	96	97	193	265	291
1921	350	326	248	200	232	225	165	158	136	237	317	323
1922	380	288	252	209	302	283	226	180	152	277	388	459
1923	502	398	404	295	357	354	279	189	189	377	500	563
1924	624	494	456	401	358	333	312	180	158	300	427	735
1925	605	443	351	334	294	304	238	155	196	361	466	626
1926	500	359	411	329	317	317	298	204	221	354	518	669
1927	579	383	416	350	348	362	281	193	191	357	556	678
1928	651	570	463	304	302	274	191	110	174	369	455	587
1929	577	428	357	294	282	287	252	164	256	415	514	571
1930	562	435	357	367	328	322	243	215	287	450	490	519
1931	586	487	409	364	325	305	263	233	367	536	703	759

WISCONSIN

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	208	101	84	85	109	107	83	70	91	192	272	248
1921	202	140	114	100	105	103	77	90	135	239	293	230
1922	188	97	104	101	112	101	79	75	100	259	311	223
1923	205	145	141	149	150	114	99	88	127	289	365	304
1924	255	145	131	164	133	105	91	72	95	255	333	318
1925	197	116	103	106	80	86	71	57	110	255	240	262
1926	193	122	127	130	113	123	98	99	149	217	328	262
1927	197	131	161	151	136	117	83	102	185	279	357	264
1928	222	158	146	122	125	95	73	51	94	267	278	262
1929	218	130	113	124	96	82	77	73	141	304	264	195
1930	139	113	103	119	96	81	76	76	180	295	275	208
1931	154	130	123	131	94	87	72	97	224	301	293	215

IOWA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	1,127	702	803	614	867	837	689	587	460	439	602	939
1921	1,032	949	701	661	648	849	725	640	544	520	696	1,020
1922	1,048	895	785	578	763	915	781	667	632	584	805	1,236
1923	1,358	1,207	1,206	962	959	1,101	1,176	1,024	780	909	1,167	1,467
1924	1,532	1,443	1,250	938	952	1,100	1,133	788	652	781	1,328	1,849
1925	1,694	1,229	789	687	697	897	726	618	633	706	927	1,281
1926	1,317	1,014	1,036	786	760	845	852	811	671	610	796	1,178
1927	1,337	969	1,119	744	934	1,169	953	938	599	645	894	1,249
1928	1,565	1,752	1,575	865	1,016	1,001	851	689	571	783	1,004	1,455
1929	1,567	1,380	888	789	863	918	1,018	835	755	851	1,066	1,499
1930	1,531	1,253	960	875	913	1,021	949	793	699	800	1,063	1,364
1931	1,766	1,353	1,088	891	922	941	866	725	764	910	1,205	1,731

MISSOURI

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	402	232	275	140	336	265	190	206	187	238	390	352
1921	355	272	201	255	322	375	231	253	243	283	429	367
1922	310	242	236	246	396	391	276	306	291	394	509	511
1923	429	330	329	331	435	344	346	359	430	649	617	551
1924	518	378	313	312	383	396	347	320	348	474	452	511
1925	432	268	222	267	317	336	293	275	356	381	339	354
1926	288	217	248	250	310	346	329	314	277	338	403	346
1927	324	242	258	279	441	438	332	362	271	355	414	412
1928	463	416	302	287	409	353	292	313	355	484	462	521
1929	423	296	260	326	412	371	406	347	390	440	437	382
1930	350	238	267	347	378	327	328	246	297	405	360	392
1931	355	281	234	302	340	263	214	219	261	315	348	391

SOUTH DAKOTA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	181	147	171	173	225	212	160	72	57	107	154	127
1921	174	188	213	145	150	208	164	125	97	126	122	168
1922	210	173	175	133	181	215	216	155	148	149	200	286
1923	356	289	304	195	273	327	304	212	144	211	217	302
1924	361	332	329	253	285	315	322	205	139	177	208	395
1925	383	337	280	236	244	258	206	161	154	184	273	347
1926	351	255	240	193	177	218	212	165	111	154	259	325
1927	341	203	237	162	158	211	183	103	67	112	141	232
1928	369	415	397	257	279	291	226	158	131	139	205	347
1929	431	313	236	242	219	225	226	153	123	188	263	360
1930	437	306	228	225	204	244	221	148	138	162	294	359
1931	518	353	261	231	208	262	266	176	188	273	514	411

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TABLE 8.—*Hogs: Marketings from individual States, 1920–1931*—Continued

NEBRASKA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	398	277	471	375	407	378	295	213	139	119	155	209
1921	367	447	373	314	331	369	310	232	158	183	213	288
1922	450	406	367	320	406	454	362	321	250	202	233	395
1923	576	550	694	556	484	507	588	502	308	296	315	438
1924	592	646	695	578	618	666	646	455	344	288	347	638
1925	790	697	520	456	486	612	412	345	301	254	341	455
1926	570	451	545	431	403	436	379	382	280	301	310	387
1927	573	460	550	380	428	441	396	368	222	191	180	257
1928	541	740	778	472	518	534	427	411	282	206	258	520
1929	695	670	524	547	511	509	496	364	294	281	355	502
1930	752	684	489	448	479	455	458	355	262	242	265	429
1931	711	606	491	414	448	498	448	371	301	318	444	688

KANSAS

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920	211	146	172	115	210	160	75	78	72	98	161	132
1921	160	192	141	148	201	189	108	122	96	109	152	144
1922	201	181	149	160	243	257	135	162	134	196	261	267
1923	311	241	253	264	313	245	172	213	254	332	316	319
1924	373	283	220	288	276	266	170	161	178	258	233	331
1925	283	243	163	195	233	257	172	143	193	173	171	193
1926	187	138	190	209	213	197	144	146	147	177	196	193
1927	220	164	168	186	240	200	120	120	108	143	148	137
1928	224	270	219	187	283	249	157	167	178	181	174	222
1929	306	251	214	275	308	296	246	255	237	271	253	277
1930	311	266	216	282	321	284	202	168	183	216	192	234
1931	279	231	188	218	266	234	149	156	170	185	158	233

TABLE 9.—*Corn* [1] *and hog series, 1880–1932*

Year	Corn acreage [2] in—		United States corn production [4]	Hog numbers on farms, January 1 [5] in—				Commercial hog slaughter [8]	Hog receipts at Chicago [9]
	United States	Cotton Belt [3]		United States	Corn Belt [6]	Cotton Belt [3]	Pacific coast [7]		
	1,000,000 acres	*1,000,000 acres*	*1,000,000 bushels*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*
1880	62	----------	1,717	34,034	----------	----------	----------	15,358	6,761
1881	64	----------	1,195	36,248	----------	----------	----------	13,683	5,962
1882	66	----------	1,617	44,122	----------	----------	----------	13,002	5,449
1883	68	----------	1,551	43,270	----------	----------	----------	13,893	5,386
1884	70	----------	1,796	44,201	----------	----------	----------	16,158	6,441
1885	73	----------	1,936	45,143	----------	----------	----------	17,913	7,190
1886	76	----------	1,665	46,092	----------	----------	----------	15,086	5,704
1887	72	----------	1,456	44,613	----------	----------	----------	16,440	5,515
1888	76	----------	1,988	44,347	----------	----------	----------	17,682	5,330
1889	72	----------	1,999	50,302	----------	----------	----------	22,225	7,199
1890	70	----------	1,460	51,603	----------	----------	----------	21,268	8,285
1891	74	----------	2,056	50,625	----------	----------	----------	23,374	8,619
1892	73	----------	1,714	52,398	----------	----------	----------	17,023	6,226
1893	74	----------	1,708	46,095	----------	----------	----------	18,954	6,868

[1] The Division of Crop and Livestock Estimates will publish revised corn acreage and production series in the near future. The differences between the year-to-year changes in the old and the new series, however, are not expected to be such as to significantly affect any of the analyses presented in this bulletin.

[2] As reported in the 1932 Yearbook of the United States Department of Agriculture.

[3] The States included are: Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Texas, and Oklahoma.

[4] Estimates of the crop reporting board of the equivalent production of grain on entire acreage grown for all purposes as reported in the 1932 Yearbook.

[5] Prior to 1900 estimates for each 10-year period represent an index of annual changes applied to census data. 1900–1919 data are tentatively revised estimates as first published in the 1927 Yearbook. 1920–1932 data are revised estimates as first published in the 1932 Yearbook.

[6] The States included are: Ohio, Indiana, Illinois, Minnesota, Wisconsin, Iowa, Missouri, South Dakota, Nebraska, and Kansas.

[7] The States included are: California, Oregon, and Washington.

[8] Total for hog-year from October through September. Prior to 1907, commercial slaughter as estimated by the Division of Livestock, Meats, and Wool on the basis of eastern and western slaughter data and market-receipts data. Subsequent data are number slaughtered under Federal inspection.

[9] Total for hog-year from October through September. Compiled from the Drovers Journal Year Book of Figures for 1928 and subsequent data of the Division of Livestock, Meats, and Wool.

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TABLE 8.—*Corn and hog series, 1880–1932*—Continued

Year	Corn acreage in—		United States corn production	Hog numbers on farms, January 1 in—				Commercial hog slaughter	Hog receipts at Chicago
	United States	Cotton Belt		United States	Corn Belt	Cotton Belt	Pacific coast		
	1,000,000 acres	*1,000,000 acres*	*1,000,000 bushels*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*	*1,000 head*
1894	69	----------	1,340	45,206	----------	----------	----------	20,890	7,608
1895	86	----------	2,311	44,166	----------	----------	----------	23,013	8,081
1896	87	----------	2,503	42,843	----------	----------	----------	25,092	8,103
1897	88	----------	2,145	40,600	----------	----------	----------	28,597	8,531
1898	88	----------	2,261	39,760	----------	----------	----------	29,980	8,716
1899	95	----------	2,455	[10] 38,652	----------	----------	----------	28,972	7,979
1900	95	----------	2,505	52,600	----------	----------	----------	30,272	8,066
1901	95	----------	1,614	53,200	----------	----------	----------	27,999	8,285
1902	96	----------	2,619	46,800	----------	----------	----------	27,041	7,490
1903	91	----------	2,347	47,200	----------	----------	----------	28,555	7,224
1904	93	----------	2,529	49,500	----------	----------	----------	31,804	7,628
1905	94	----------	2,749	52,000	----------	----------	----------	32,880	7,634
1906	94	----------	2,898	54,600	----------	----------	----------	33,251	7,208
1907	95	----------	2,512	57,300	----------	----------	----------	34,774	7,525
1908	96	----------	2,545	61,300	----------	----------	----------	34,425	7,337
1909	98	----------	2,572	57,000	----------	----------	----------	27,167	5,613
1910	104	----------	2,886	49,300	----------	----------	----------	31,305	6,721
1911	106	----------	2,531	55,700	----------	----------	----------	34,130	7,375
1912	107	----------	3,125	55,700	----------	----------	----------	33,316	7,158
1913	106	----------	2,447	54,000	----------	----------	----------	32,298	6,830
1914	103	----------	2,673	51,800	----------	----------	----------	36,707	7,205
1915	106	----------	2,995	57,000	----------	----------	----------	41,393	8,621
1916	105	35	2,567	59,700	----------	----------	----------	38,315	8,210
1917	117	38	3,065	56,700	----------	----------	----------	37,214	7,970
1918	104	36	2,503	61,200	----------	----------	----------	44,024	8,830
1919	97	31	2,811	63,800	----------	----------	----------	38,966	7,969
1920	102	31	3,209	60,159	34,729	15,802	1,441	38,662	7,899
1921	104	34	3,069	58,942	35,469	14,829	1,302	40,383	8,036
1922	103	32	2,906	59,849	37,239	14,330	1,250	50,612	9,723
1923	104	30	3,054	69,304	46,937	13,632	1,286	53,706	10,348
1924	101	27	2,309	66,576	46,284	11,772	1,115	46,289	9,075
1925	101	25	2,916	55,770	38,757	9,875	953	41,150	7,238
1926	100	25	2,692	52,085	36,297	9,158	859	43,090	7,542
1927	98	27	2,763	55,468	38,543	9,827	1,028	47,370	8,387
1928	101	26	2,819	61,772	42,703	11,179	1,178	48,957	8,154
1929	98	25	2,535	58,789	40,695	10,609	1,094	45,542	7,910
1930	101	26	2,060	55,301	38,632	9,875	958	43,559	7,686
1931	105	28	2,563	54,374	38,531	9,418	948	46,656	7,485
1932	----------	----------	----------	59,511	41,378	11,072	1,176	----------	----------

Bureau of Agricultural Economics.

[10] Original estimate and not to be compared with revised estimate for 1900. See footnote 5 on page 52.

TABLE 10.—*Changes in the price of hogs* [1] *from Monday to Tuesday and changes in truck receipts of hogs from Tuesday to Wednesday at Sioux City, 1929–30*

Changes in price from Monday to Tuesday (cents per 100 pounds)	Frequency	Truck receipts on—		Percentage change in truck receipts
		Monday	Tuesday	
		Number	*Number*	*Per cent*
−35	3	11,816	8,396	−29
−25	8	60,971	34,063	−44
−15	23	159,952	106,621	−33
−5	21	123,153	88,258	−28
0	9	55,981	50,309	−10
+5	25	144,860	145,966	+1
+15	7	45,791	46,459	+1
+25	3	11,630	14,406	+24
+35	4	23,580	32,756	+39

Compiled from records of the Division of Livestock, Meats, and Wool.

[1] Average price of medium-weight hogs.

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TABLE 11.—*Changes in the price of hogs* [1] *from Saturday to Monday and changes in hog receipts from Monday to the following Thursday at Chicago, 1929–30*

Changes in price from Saturday to Monday (cents per 100 pounds)	Frequency	Market receipts on—		Percentage change in receipts
		Monday	Thursday	
		Number	*Number*	*Per cent*
−25	7	336,398	132,906	−60
−20	6	298,081	128,943	−57
−15	5	297,593	91,726	−69
−10	8	467,981	223,469	−52
−5	8	488,928	292,961	−40
0	12	530,581	298,500	−44
+5	13	667,365	402,826	−40
+10	12	521,425	345,430	−34
+15	11	454,321	320,937	−29
+20	6	305,959	227,683	−26
+25	1	56,172	49,291	−12
+30	4	136,037	101,056	−26
+35	2	68,671	50,509	−26
+40	1	31,884	62,989	+98

Compiled from records of the Division of Livestock, Meats, and Wool.

[1] Average prices as compiled by the Chicago Daily Drovers Journal and published in the annual Drovers Journal Yearbook.

TABLE 12.—*Results of spring and fall pig surveys for the Corn Belt* [1] *and the United States, 1923–1930*

Year and area	June survey				December survey			
	Sows that farrowed as compared with number that farrowed the preceding spring		Pigs saved		Sows that farrowed as compared with number that farrowed the preceding spring		Pigs saved	
	Intended [2]	Actual	Compared with preceding spring	Per litter	Intended [2]	Actual	Compared with preceding fall	Per litter
1923:	*Per cent*	*Per cent*	*Per cent*	*Number*	*Per cent*	*Per cent*	*Per cent*	*Number*
Corn Belt	115.9	108.1	105.0	4.84	125.5	93.9	96.2	5.02
United States	113.1	103.9	100.9	4.98	128.3	91.3	93.2	5.07
1924:								
Corn Belt	94.6	79.7	82.9	5.20	88.6	69.4	76.6	5.47
United States	98.8	78.8	80.2	5.17	94.1	71.8	77.8	5.45
1925:								
Corn Belt	89.6	80.1	89.4	5.78	100.9	85.4	87.8	5.72
United States	94.3	81.2	91.3	5.79	104.5	84.6	88.1	5.73
1926:								
Corn Belt	111.1	103.5	99.5	5.54	136.4	104.8	104.3	5.68
United States	111.9	101.7	98.8	5.58	139.0	102.4	103.0	5.77
1927:								
Corn Belt	108.9	101.8	101.8	5.55	123.1	109.3	111.3	5.88
United States	113.2	103.0	103.5	5.62	129.9	110.2	111.0	5.86
1928:								
Corn Belt	101.3	91.0	93.0	5.64	109.1	96.0	98.6	6.04
United States	105.8	92.3	92.9	5.63	111.7	93.3	94.7	5.96
1929:								
Corn Belt	103.3	92.3	93.9	5.72	117.1	102.8	103.7	6.05
United States	105.4	90.3	91.6	5.67	117.8	98.1	99.8	6.02
1930:								
Corn Belt	105.1	92.8	97.1	5.99	115.5	100.9	102.4	6.14
United States	106.0	90.3	94.3	5.97	118.2	97.4	98.8	6.09
1931:								
Corn Belt	109.9	102.6	103.7	6.06	135.3	121.5	121.0	6.07
United States	112.2	101.4	102.5	6.04	137.0	119.5	119.7	6.07

Division of Crop and Livestock Estimates.

[1] The States included are: Michigan, Ohio, Indiana, Illinois, Minnesota, Wisconsin, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas.

[2] As shown by preceding survey.

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TABLE 13.—*Distribution of sows that farrowed in the Corn Belt* [1] *by size of sow herd* [2] *as shown by the December pig survey, 1926*

Farms reporting (number)	Acres per farm	Sows that farrowed per farm in—			Sows to farrow per farm in spring of 1927
		Spring of 1926	Fall of 1925	Fall of 1926	
		Number	*Number*	*Number*	*Number*
3,939	196	0	2.5	2.1	2.6
4,987	139	1.0	1.0	1.1	1.7
4,847	148	2.0	1.6	1.7	2.6
3,328	157	3.0	2.1	2.3	3.7
3,040	169	4.0	2.6	2.7	4.6
2,300	178	5.0	3.1	3.2	5.7
2,130	181	6.0	3.4	3.4	6.5
1,507	184	7.0	3.8	3.6	7.8
1,814	194	8.0	3.8	3.7	8.4
909	206	9.0	3.6	3.9	9.2
1,674	211	10.0	3.9	4.0	10.5
526	213	11.0	4.2	4.5	11.3
1,179	224	12.0	3.9	4.1	12.1
337	223	13.0	3.7	4.2	13.6
601	237	14.0	4.0	4.7	13.6
752	244	15.0	4.4	4.7	14.5
398	228	16.0	5.0	5.1	15.3
245	239	17.0	4.2	5.2	16.6
394	244	18.0	4.5	4.8	17.4
126	217	19.0	4.1	4.1	17.2
634	276	20.0	5.3	5.3	19.8
93	256	21.0	4.5	5.9	18.5
158	271	22.0	4.3	4.5	19.7
94	312	23.0	3.6	4.4	22.2
99	251	24.0	4.4	4.4	21.5
237	280	25.0	5.2	4.9	23.2
705	308	33.4	6.5	6.8	26.5
91	310	102.4	2.4	2.0	39.9
[3] 37,144	[3] 184	[3] 6.4	[3] 2.9	[3] 2.9	[3] 6.7

Compiled from records of the Division of Crop and Livestock Estimates.

[1] The States included are: Ohio, Indiana, Illinois, Wisconsin, Minnesota, Iowa, Missouri, South Dakota, Kansas, and Nebraska.
[2] Size as measured by the number of sows that farrowed in the spring of 1926. The class intervals for the last 2 size groups are 26 to 50 and 51 to 1,000.
[3] Total or average.

TABLE 14.—*Supply and price data for sheep, beef cattle, hogs, and butter, 1921–1931*

Year	Supply (million pounds) [1]				Price (dollars per 100 pounds) [2]			
	Sheep	Beef cattle	Hogs	Butter	Sheep	Beef cattle	Hogs	Butter
1921	493	4,453	6,732	1,055	8.57	6.77	8.52	40
1922	418	4,968	7,419	1,154	12.19	6.70	9.30	38
1923	446	5,129	9,182	1,242	12.02	6.94	7.57	45
1924	456	5,328	8,820	1,356	12.80	6.74	8.04	40
1925	466	5,480	7,323	1,362	14.02	7.27	11.81	44
1926	501	5,757	7,273	1,452	12.84	7.55	12.47	42
1927	502	5,278	7,731	1,496	12.97	8.81	10.03	45
1928	523	4,727	8,579	1,487	13.53	10.75	9.20	46
1929	545	4,728	8,430	1,597	13.24	10.76	10.08	43
1930	650	4,704	7,718	1,565	8.98	8.66	9.40	35
1931	687	4,751	7,831	1,622	7.04	6.32	6.12	26

Division of Livestock, Meats, and Wool.

[1] Production of dressed meat from Federally-inspected slaughter of sheep and lambs, veal calves and beef cattle, and hogs; and factory butter production, as reported to the Bureau of Agricultural Economics.
[2] Weighted average cost per live hundredweight to the packers of animals slaughtered under Federal inspection, and weighted average wholesale price of 92-score butter at Chicago.

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LITERATURE CITED

(1) Bean, L. H.
1929. A SIMPLIFIED METHOD OF GRAPHIC CURVILINEAR CORRELATION. Jour. Amer. Statis. Assoc. (n. s. 168) 24: 386–397, illus.

(2) Elliott, F. F.
1927. ADJUSTING HOG PRODUCTION TO MARKET DEMAND. Ill. Agr. Expt. Sta. Bul. 293, p. 501–567, illus.

(3) Haas, G. C., and Ezekiel, M.
1926. FACTORS AFFECTING THE PRICE OF HOGS. U. S. Dept. Agr. Bul. 1440, 68 p., illus.

(4) Russell, S. W.
1929. FORECASTING HOG PRODUCTION AND MARKETING. Jour. Amer. Statis. Assoc. (n. s. 165A) 24 (Sup.): 225–233, illus.

(5) Stover, H. J.
1930. EFFECT OF CHANGES IN DAILY PRICES ON THE MOVEMENT OF FARM PRODUCE TO TERMINAL MARKETS. Internatl. Conf. Agr. Econ. Proc. 2: 777–783, illus.

(6) Thomsen, F. L., and Richards, P.
1930. A PARTIAL ANALYSIS OF THE MISSOURI PIG SURVEY REPORTS. Missouri Agr. Expt. Sta. Research Bul. 139, 34 p., illus.

(7) United States Department of Agriculture, Bureau of Agricultural Economics.
1924–1931. THE AGRICULTURAL OUTLOOK. 1924–1931. U. S. Dept. Agr. Misc. Circs. 23, 38, 65, and 101, and Misc. Pubs. 19, 44, 73, and 108.

(8) Wright, S.
1925. CORN AND HOG CORRELATIONS. U. S. Dept. Agr. Bul. 1300, 60 p., illus.

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Technical Bulletin No. 360 May 1933

CURLY-TOP RESISTANCE IN SUGAR BEETS AND TESTS OF THE RESISTANT VARIETY U. S. NO. 1

BY

EUBANKS CARSNER

Senior Pathologist
and other members of the Division of
Sugar Plant Investigations, Bureau of Plant Industry

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 360 MAY 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

CURLY-TOP RESISTANCE IN SUGAR BEETS AND TESTS OF THE RESISTANT VARIETY U. S. No. 1

By EUBANKS CARSNER

Senior Pathologist, and other members of the Division of Sugar Plant Investigations, Bureau of Plant Industry [1]

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INTRODUCTION [2]

ECONOMIC IMPORTANCE OF CURLY TOP

Curly top of sugar beets (*Beta vulgaris* L.) was first recognized as a disease of major economic importance in 1899, in California. Since that time frequent and often very destructive outbreaks have occurred in practically all the sugar-beet areas west of the Rocky Mountains, except a few districts in the fog belt along the Pacific coast. Its occurrence in serious amounts east of the Continental Divide has apparently been restricted to certain sections in the Southwest, such as New Mexico, western Texas, and southern Colorado. The beet areas in northern Colorado east of the Rocky Mountains, as well as those in Nebraska, Kansas, Wyoming, and South Dakota, have been free from the disease or have shown only sporadic

[1] These contributions were made by F. A. Abegg, associate geneticist; C. E. Cormany, associate agronomist; H. A. Elcock, assistant pathologist; Wesley Keller, agent; C. C. Lowe, assistant agronomist; F. V. Owen, geneticist; D. A. Pack, associate agronomist (resigned, Nov. 30, 1929); Charles Price, associate agronomist; and A. W. Skuderna, principal agronomist. Responsibility for the various contributions is indicated in the respective sections. The agronomic tests in California, Idaho, and New Mexico were carried on under the general supervision of A. W. Skuderna. Acknowledgment is made to G. H. Coons, principal pathologist, for assistance in the preparation of the manuscript.

[2] Contributed by Eubanks Carsner.

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incidence not serious in amount. In the regions where it occurs as epidemics curly top is the most destructive of all beet diseases. In several of the important agricultural districts west of the Rocky Mountains this disease is the principal factor limiting the beet crop. Curly top is a virus disease. The causal virus is transmitted by the beet leaf hopper, *Eutettix tenellus* (Baker). The geographic distribution of the disease is therefore the same as that of the insect vector.

Investigators have emphasized direct financial losses due to curly top. Adequate recognition should be given also to the effect on western agriculture of the abandonment of the sugar-beet crop in large areas. The sugar beet is generally recognized as an important and valuable crop in the agricultural system for these regions, not alone because it is an intensively cultivated cash crop, but because through its valuable by-products, namely, beet pulp, beet tops, and

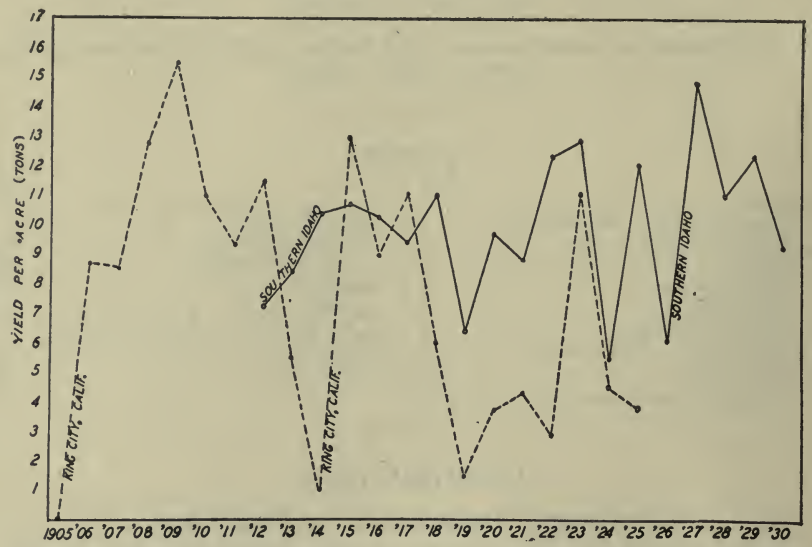

FIGURE 1.—Average yields of sugar beets in tons per acre for 1905–1930 in the King City district of California and in southern Idaho. The serious decreases in yields were caused by curly-top injury

beet molasses, it fosters the dairying and stock-feeding industries. Control of the curly-top disease will contribute greatly to a stabilization of sugar-beet growing in large areas where it is now continually menaced, and will thus have far-reaching effects upon the general farm situation in the West. If curly-top control is assured, it will be possible for the beet-sugar industry to return to districts previously abandoned because of curly top; and it will bring about, as economic conditions warrant, expansion into regions heretofore avoided because of the curly-top hazard.

Figure 1 shows the average yields of sugar beets in tons per acre for a series of years in two representative western areas where curly-top outbreaks have occurred, namely, King City, Calif., and southern Idaho. This chart indicates the decrease in yields in years of serious outbreaks and the potential production if this disease factor is over-

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come. In the California district, for example, in the years 1909, 1912, 1915, and 1917, which were relatively free from curly top, the average yields were 15.6, 11.5, 13.0, and 11.3 tons per acre, respectively, in contrast with the disastrous curly-top years 1914 and 1919, when the yields were 1.0 and 1.4 tons per acre, respectively. Similarly, in southern Idaho, such years as 1923, 1925, 1927, and 1929, relatively free from curly top, and with average yields of 12.9, 12.1, 14.9, and 12.4 tons per acre, respectively, may be contrasted with the years 1924 and 1926, in which serious curly top occurred and in which the yields were 5.5 and 6.0 tons per acre, respectively. It must be remembered that even in the years classed as "relatively free from curly top" the disease caused an economically significant degree of crop reduction.

METHODS OF CONTROL

CONTROL OF THE BEET LEAF HOPPER

When it was shown that the beet leaf hopper is probably the sole natural agency of transmission of the curly-top virus, the control of the insect was suggested as a means of preventing or mitigating curly-top damage. Extended entomological research has been conducted in the effort to effect control of the insect. Attacks on the leaf hoppers with insecticides and mechanical means have, in the past, been conducted mainly in sugar-beet fields. Such methods, however, have not proved very effective in reducing curly-top damage.

The problem has also been approached, in recent years, from the standpoint of insect ecology, with the result that intensive research has developed a body of knowledge on the factors influencing the size of leaf-hopper populations in the fall, their survival through the winter, the spring increases, and the migration period (*6*).[3] From such data and from past records of beet production it is possible to predict the probable populations in the spring and the period of migration, in certain areas intensively studied. Such predictions have been valuable in making it possible to avoid planting beets in years of heavy leaf-hopper influx.

Related to this phase of control is the study of the plants that harbor the insect in the natural breeding grounds. The beet leaf hopper has been found to be strongly influenced by introduced weeds now established on the abandoned farms and in desert areas surrounding those now cultivated; this flora determines in large measure the distribution and size of populations of the insect. Reduction of the weeds in which the beet leaf hopper multiplies and which are otherwise objectionable is a procedure obviously commendable aside from its bearing on curly-top control. The possibility of developing beneficial practices through an ecological study of the weed hosts of the insect was pointed out by Carter (*6*). A study of the plant successions in these natural breeding grounds by Piemeisel (*12*) has indicated the possibility of replacing the introduced plants with the natural vegetation, which is less favorable for the leaf-hopper populations.

[3] Italic numbers in parentheses refer to Literature Cited, p. 68.

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CULTURAL PRACTICES

In addition to the general measures, which involve large areas and are necessarily slow and gradual in their influence, various cultural practices are definitely applicable to curly-top control.

Of these cultural practices the most important is timing the planting of the beets so as to get the crop advanced as far as possible before the spring influx of the beet leaf hopper. In California, Idaho, and Utah such procedure has resulted in great benefit. Associated with this measure are other desirable agronomic practices, such as the effective use of irrigation water and the application of necessary fertilizers. In general, it has been found that fields in which the size and vigor of the plants have been increased by early planting and excellent cultural practices have suffered less damage than fields in which the plants were very young or in an unthrifty condition at the time of the leaf-hopper influx.

All the measures mentioned, however, are to be regarded as palliative rather than as affording a completely satisfactory control. Nevertheless, for the present at least, it is urgent that all helpful practices be continued because of their contribution to the lessening of the injury from the curly-top disease.

USE OF RESISTANT VARIETIES

The use of resistant varieties for the control of plant diseases has long been recognized as a very desirable measure and the one to be preferred where sanitation or modified cultural practices fail to give adequate relief. In the case of curly top this method of control appears to have been the first one considered. The progress heretofore made in the development of resistant varieties may be briefly reviewed.

Townsend (*14*) began selecting sugar beets for resistance to curly top in 1902. His efforts were handicapped because the relationship of the beet leaf hopper to the disease had not then been demonstrated and therefore no way of insuring exposure of the plants to the disease was known. In one trial, however, in 1907, he reports evidence of an appreciable degree of resistance in the progeny of plants selected for resistance, as compared with 25 other varieties. The work along this line was interrupted, and no further progress was reported.

Carsner (*5*) reported selection efforts that were begun in 1918 and continued through the season of 1925. Primary emphasis was placed on securing beets resistant to the disease in the hope that, if such plants were found or developed, the required quality as to sugar content could, if necessary, be later secured by breeding. Strains varying from a moderate to a very high degree of resistance were obtained, and the fact was demonstrated that resistance to curly top is a heritable character. The extremely resistant strains proved to be very low in sugar content. No further data have been presented, but in the report of the Chief of the Bureau of Plant Industry (*13, p. 18*) issued December 3, 1929, the following statement appears: "Extensive tests demonstrated that some varieties of beets sufficiently resistant to give good yields in spite of curly top are also satisfactory from the standpoint of sugar content."

Esau (*8*) reported work on selection and breeding for curly-top resistance that had been carried on continuously from 1919 to 1929.

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A strain derived from a resistant mother beet isolated in a cloth cage in 1920 was subjected to repeated tests for resistance, and attempts were made to improve it and purify it by repeated reselection. The fact was conclusively demonstrated that this strain was highly resistant and that this character was inherited. The strain was not found satisfactory for commercial use, but its value for breeding purposes was recognized. It was hybridized with another highly resistant strain (obtained from Carsner) and also with a strain (obtained from Pack) which was of high sugar quality but not highly resistant. The results indicated possibilities of progress through breeding. Mass-selection studies also demonstrated the possibility of developing by this method varieties sufficiently resistant to afford very substantial increases in yield over susceptible commercial brands. The sugar percentages in these varieties were practically the same as that of the commercial variety used for comparison. Their total sugar content was of course much greater.

Coons, Stewart, and Elcock (7) reported progress in work on the selection of resistant sugar beets and the use of such individuals either to develop inbred lines or to produce seed by being planted in groups. Progenies obtained by the latter method (mass selection) produced more than three times the yield of the commercial variety under curly-top conditions, but were regarded as not yet sufficiently resistant for commercial use under severe conditions. These investigators also reported results obtained from numerous European collections of the wild beet (*Beta maritima* L.). Individuals of *B. maritima* were found which were so nearly immune to curly top as to make it very difficult to detect symptoms on them and which were also acceptable as to percentage of sucrose. These highly resistant individuals were crossed with high-grade nonresistant commercial beets, and the hybrid material was tested. In one test the hybrid yielded approximately eight times as much as the commercial brand used as a check.

DEVELOPMENT OF RESISTANT VARIETY U. S. NO. 1 [4]

This report on curly-top resistance in sugar beets as a control measure represents a continuation and expansion of the effort begun in 1918. As previously noted, the results up to 1926 have already been published. In the present report evidence is presented of an important advance in the development of a commercially desirable variety resistant to curly top (U. S. No. 1); but a very resistant variety of as high quality as is desirable has not yet been obtained, though further improvement may be expected from continued effort in this direction. From 1926 to 1929 the work was carried on through the cooperation of the contributors of this section. In 1929 the staff of investigators was enlarged and reorganized. Most of the additional workers have contributed parts of this report. The various phases of the resistance project are being continued by the several groups of workers. Selection and breeding for further improvement are being pushed by the geneticists; the agronomists are conducting the critical evaluation of the resistant varieties and studying the factors

[4] Contributed by Eubanks Carsner and Dean A. Pack.

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involved in growing the seed; and the pathologists and the chemists are studying the nature of resistance in the sugar beets. Progress is being made also on an analysis of the basic physiological factors involved in seed production.

The U. S. No. 1. variety [5] is not the only resistant material that has been selected and studied in the course of the present investigation. Several lines selected from strains that were combined to produce the present variety appear to be equal or superior to it. The variety discussed herein was developed by a combination of the most promising strains available in 1928. It was thus produced as quickly as possible in order to meet promptly the emergency in the industry due to curly top and in the hope that it would afford a measure of control while resistant varieties superior to it were being developed. Because this is the first resistant variety to be released by the United States Department of Agriculture for commercial use in the curly-top areas, it has been designated "U. S. No. 1."

The selections combined to produce the U. S. No. 1 variety were obtained mainly from a field of resistant strains grown at Twin Falls, Idaho, in 1928.[6] This location was chosen in order that the plants might be naturally exposed to curly-top infection. The chief purpose of the planting was to obtain from the available seed the greatest possible number of plants for extensive and critical reselection. Accordingly, men were employed to plant the seed by hand in order to spread it farther than would have been possible by the use of the beet drill. A total area of slightly over 5 acres was used for the planting. As a measure of the degree of curly-top exposure, eight 4-row plots running the full length of the field were drilled in with a commercial brand of seed. The degree of disease exposure obtained is indicated by the fact that the average yield from the test plots of the commercial brand was slightly less than 12 tons per acre as compared with a commercial yield from the same field in the preceding year of 25 tons per acre.

Included in this 1928 planting at Twin Falls were all the resistant strains and hybrids then available. Some of these, while extremely resistant, were too low in sugar content to be commercially satisfactory. They were included for selection purposes in connection with the continuing breeding program, but none of the roots selected from these strains was included in the seed-beet field of 1929, where the initial lot of seed of the U. S. No. 1 variety was grown. The history and description of the strains used to produce the U. S. No. 1 variety are given later.

The selections of resistant strains at Twin Falls were made at harvest time, October, 1928.[7] Plants were chosen first which were of satisfactory root shape and which on the basis of root size and foliage reaction appeared most resistant. The roots thus selected in the field were taken to the laboratory and individually tested by means of

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[5] The term "variety" is used in conformance with common usage in sugar-beet publications and indicates in this paper a complex combination of sugar-beet types chosen on the basis of curly-top resistance and commercial qualities. It does not imply the distinct morphological uniformity which characterizes taxonomic or horticultural varieties.

[6] Albert M. Murphy, Scientific Aide, Division of Sugar Plant Investigations, assisted with the field work at Twin Falls.

[7] Thanks are due Walter Carter, at that time senior entomologist, Division of Truck Crop Insects Bureau of Entomology, for assistance in the fall and winter operations.

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the refractometer. Of the 9,051 roots tested, 5,811 were retained, those reading lowest in percentage of dry substance being rejected. Of the roots saved, those which gave the higher refractometer readings were analyzed by means of the polariscope; approximately 400 beets were thus selected for further breeding work.

STRAIN 5001

Of the selected roots entering into the planting that produced the U. S. No. 1 variety, the largest lot was obtained from the strain designated in the field notes as 5001. This strain was derived from an extensive mass selection made from severely affected fields in Idaho and Utah during the curly-top epidemic of 1926. Approximately 1,500 individuals were selected on the basis of resistance and root shape, and these were planted in large groups for seed production in 1927. Strain 5001 constituted approximately one-fourth of the resistant strains planted at Twin Falls in 1928. It was thus possible to make extensive selections from this strain.

WASHINGTON STRAIN

The next largest component of the U. S. No. 1 variety was the selection termed in the writers' notes "the Washington strain." This strain was derived from a relatively large primary mass selection made from commercial fields in the Yakima Valley, Wash., in 1923, by employees of the Utah-Idaho Sugar Co. under the direction of the company's district manager, J. W. Timpson. Under the same auspices, seed was grown from the selected roots at Toppenish, Wash., in 1924. A test of the progeny of this primary selection, as conducted at Riverside, Calif., in 1925, has been previously reported (*5*). The selections from the Riverside plots reported on here, 37 roots, were planted in a group in November, 1925. Six of the thirty-seven plants produced seed in 1926.

In connection with tests of other strains at Riverside in 1927,[8] resistance tests were made on seed from the six mother beets that bloomed in 1926. The seed was planted in single-row plots 50 feet long, alternating with check plots of a commercial brand. For one of the Washington selections there was only one plot; for four of them there was enough seed for duplicate plantings; and for one there were three replications. The beets were inoculated by caging two viruliferous beet leaf hoppers on each plant soon after thinning. At harvest the Washington selections gave average yields ranging from 69 to 102 pounds per plot, the average for the 12 plots being 81 pounds per plot. The average yield from 75 commercial check plots was 39 pounds per plot. As calculated on an acre basis, the Washington selections yielded 17.6 tons per acre; the commercial brands, 8.5 tons per acre. In the Washington plots practically no plants died after thinning, whereas 23 per cent of the commercial plants died. Curly top undoubtedly was the main factor responsible for this result. No sugar determinations were made of the commercial brand used as a check, and of the resistant strains only those roots were analyzed which had been selected for resistance. Since the

[8] Acknowledgment is due Charles F. Lackey, assistant pathologist, Division of Sugar Plant Investigations, for assistance with the experimental work at Riverside, Calif.

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roots were selected mainly on the basis of size, their sugar content may have been somewhat lower than that of the beets in the plots as a whole would have run. Approximately one-third, or 213, of the Washington beets were analyzed. The six lots averaged from 13.9 to 17.0 per cent sucrose, the general average being 15.1 percent. The plants of the Washington strain in these and subsequent tests had predominantly dark-green foliage. This characteristic is useful in identifying the strain.

The group of old mother beets selected in 1925 was maintained in the same place for seed production a second year. A sufficient number of plants survived the second year to make it possible to obtain seed from 14 separate mother beets in 1927, including some that had produced seed in 1926. These lots of seed were included in the 1928 planting at Twin Falls, Idaho. Three random agronomic samples from the Washington strain at harvest, 22 roots in all, gave an average weight of 2.04 pounds per beet and an average sucrose percentage of 17.1 per beet. Three comparable samples from the commercial checks, 21 roots in all, gave averages of 1.5 pounds in weight and 16.9 per cent of sucrose per beet.

905a2 STRAIN

Another strain used in producing the U. S. No. 1 variety was the inbred line 905a2. This strain was derived from a mother beet selected by Eubanks Carsner and C. F. Stahl, entomologist, Division of Truck Crop Insects, Bureau of Entomology, from a severely exposed field of the Spreckels Sugar Co. at King City, Calif., in September, 1922. Progenies from this selection and from group plantings of subsequent reselections were tested for resistance at Riverside. In these tests, in addition to exposure by natural infestation, viruliferous beet leaf hoppers were caged on each plant. During one severe season of curly top (1926) small tests were made by natural exposure at Twin Falls, Idaho, and at Salt Lake City, Utah. This strain (905a2) consistently showed a higher sugar content than had previously been found in resistant beets, averaging about 16.5 per cent, and maintained its resistance to curly top despite loss of vigor from inbreeding. The strain possesses genetic factors that produce in many of its individuals a red stripe in the center of the upper side of the petiole. This character appears frequently in the U. S. No. 1 variety and is useful in identifying the latter. The 905a2 strain shows also an inherent tendency to bolt, that is, to develop seed stalks the first season, somewhat more readily than most commercial brands of sugar beets.

905a2 HYBRIDS

Next in order of importance among the strains combined in the U. S. No. 1 variety were several first-generation hybrids between 905a2 and other strains. The three principal hybrids resulted from crosses between 905a2 and three lines selected for high sugar quality without regard to curly-top resistance. The hybrids were 905a2 × 6A7, 905a2 × 6–4–6, and 905a2 × 202. Two other hybrids, namely, 905a2 × 7489–24 and 905a2 × 6193–24, were included in comparatively small numbers. The strains 7489–24 and 6193–24 were derived by reselection from strains first selected in northern Colorado by W. W.

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Tracy, jr., formerly of the Division of Sugar Plant Investigations. Subsequent tests at Riverside and elsewhere had shown that these strains were somewhat resistant to curly top

OTHER STRAINS INCLUDED

Three other strains were combined in the U. S. No. 1 variety. These were 6677–24, 3929, and the one designated as De Rekowski. The De Rekowski strain was originally obtained by a small-scale mass selection (17 beets) made by officials of the Amalgamated Sugar Co. at Twin Falls, Idaho, in the autumn of 1924. The roots were sent to Charles W. de Rekowski at Detroit, Mich. Some of the seed produced there from these beets was sent by De Rekowski to the Riverside station. By running this strain through another generation a limited amount of seed was available for inclusion in the 1928 planting at Twin Falls. Strain 3929 resulted from inbreeding the progeny of one mother beet out of 112 beets selected for resistance at Twin Falls in the autumn of 1924. Strain 6677–24 was developed by W. W. Tracy, jr., at Fort Collins, Colo., and was later found to be somewhat

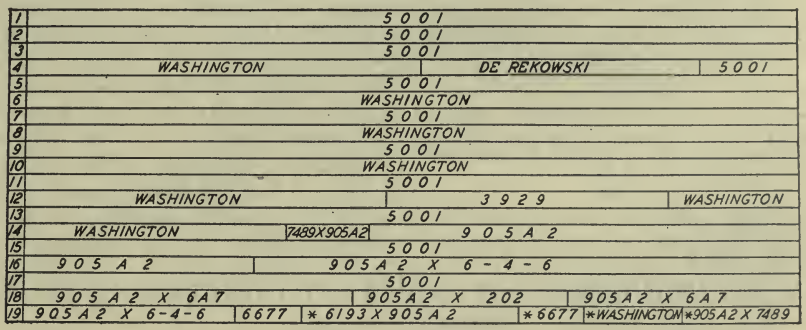

FIGURE 2.—Diagram of mother-beet planting in block A of seed-beet field at Twin Falls, Idaho, in 1929, from which the original seed of the U. S. No. 1 variety was obtained. Each horizontal line represents a row approximately 500 feet long. Rows marked * were planted with the roots from Riverside

resistant to curly top. This strain was not included in the 1928 planting at Twin Falls, but it was planted that same year under more drastic curly-top exposure at Castleford, Idaho. A small number of selected roots from that planting were included in the 1929 seed field which produced the seed of the U. S. No. 1 variety.

As shown in the chart (fig. 2), four small lots of roots grown at Riverside, Calif., during the winter of 1928–29, were also included in the seed field at Twin Falls. The relative proportion of the various strains combining to produce the U. S. No. 1 variety and their distribution in the seed-beet field are indicated on this chart. Slightly more than 4,500 mother beets were included in the plot. Of these, about 2,500 were of the strain 5001; about 1,200 were of the Washington strain; and the other strains were represented in smaller proportions.

The seed from this group planting at Twin Falls, in 1929, constituted the original seed supply of the U. S. No. 1 variety. With seed of this original lot agronomic evaluation tests were conducted on a comparatively limited scale in three localities in 1930. The results of these tests are reported in other sections of this bulletin.

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An augmented supply of seed of the U. S. No. 1 variety was produced in 1930 by the overwintering-in-the-field method of seed growing developed by the United States Department of Agriculture (*11*). The production of this seed was carried out by H. A. Elcock and J. C. Overpeck, at State College, N. Mex.; by Charles Price, at Beaumont, Calif.; and by F. V. Owen and D. A. Pack, at St. George, Utah. The increased amount of seed of the variety made possible extensive agronomic evaluation tests in 1931. Critical tests were conducted in controlled agronomic plots, and plots known as grower-test plantings were planted in the fields of farmers. The localities chosen for these tests were distributed throughout the curly-top areas in Idaho, Utah, Colorado, California, and New Mexico. This distribution afforded a wide range of soil and of climatic and cultural conditions, as well as of degrees of disease exposure. The distribution of the places where the testing was conducted is shown in Figure 3. The detailed results of these tests are reported in the following sections of this bulletin.[9]

FIGURE 3.—Location of test plantings of the U. S. No. 1 variety, in 1931, in Idaho, Utah, Colorado, California, and New Mexico

EVALUATION TESTS OF RESISTANT VARIETY U. S. NO. 1

TESTS IN IDAHO [10]

In Idaho agronomic tests were made to determine the performance of the U. S. No. 1 variety of sugar beets as compared with that of the commercial brands commonly used in the Idaho area. The tests were of three types: (1) Intensive agronomic tests on small plots replicated many times; (2) grower-test plantings, made under ordinary field conditions; and 3) comparative studies of the rate of development of the resistant and susceptible plants.

INTENSIVE AGRONOMIC TESTS

TESTS AT CASTLEFORD

In 1930 intensive agronomic tests of the U. S. No. 1 variety were begun on the experimental farm at Castleford. In these tests the original seed stock obtained from selected mothers (p. 5–9) was used. The tests were continued at Castleford in 1931 with the first multiplication of the original seed (p. 9).

The experimental farm at Castleford was selected [11] for the intensive agronomic work because of the long history of sugar-beet failures in this district. The farm chosen had not produced a profitable crop of

[9] Details as to materials and methods, where these were identical in several consecutive sections, have not been repeated.

[10] Contributed by C. E. Cormany and C. C. Lowe.

[11] The experimental work in the Castleford and Twin Falls area was carried on in cooperation with the Amalgamated Sugar Co., which provided land and other facilities for these experiments.

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sugar beets during recent years, and sugar-beet growing had been almost entirely abandoned by the farmers in the Castleford area as being too hazardous because of the curly-top menace. In 1930 and 1931 conditions in the Castleford district fully conformed to past experience. Nearly maximum curly-top exposure was obtained in 1930; in 1931 curly top, while not doing maximum damage, seriously affected the beet crop.

In 1930 the U. S. No. 1 variety was planted on the experimental farm in six plots, each four rows wide and 90 feet long, alternating with similar plots of a commercial brand (Pioneer).[12] These plots were part of a large series planted with different varieties and strains in systematic replications. As has been noted, 1930 was one of the most severe curly-top years experienced in Idaho; the Castleford district, being close to the breeding areas of the insect, was particularly affected. The plots of resistant sugar beets were conspicuous in the latter part of the season as islands of dark-green growing plants

FIGURE 4.—Curly-top-resistance tests in agronomic plots at Castleford, Idaho. At the left in the foreground (plot 1703) are four rows of the U. S. No. 1 variety. Adjacent to this on the right (plot 1704) are four rows of the commerical brand (Pioneer) which are continuous through the field. The photograph shows also replicated plots of the U. S. No. 1 variety and those of three other resistant strains being tested. Photographed September 19, 1930

(fig. 4.) surrounded by plots of dwarfed yellowish-green plants of the commercial brand. Although there was evidence of practically 100 per cent infection in the plots of the U. S. No. 1 variety and the disease had killed or rendered worthless a certain percentage of the plants, those which remained showed definite curly-top resistance.

The somewhat unfavorable soil conditions in the experimental field and the late planting undoubtedly affected yields and sucrose percentages of both the resistant variety under test and the commercial brand used as a check; these conditions, on the other hand, provided as severe a curly-top test as could be desired.

The results here given as averages (Table 1) were overwhelmingly in favor of the resistant variety (U. S. No. 1) in yields of beets and of sugar per acre, and demonstrated the curly-top resistance of the variety as a whole. It is evident, however, that the variety does not consist of uniformly reacting individuals but of individuals of various degrees of resistance. The average sucrose percentage and coefficient

[12] Produced by the Kleinwanzleben Zuckerfabrik, Kleinwanzleben, Germany.

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of purity, obtained in the comparative analyses, were likewise in favor of the U. S. No. 1 variety.

TABLE 1.—*Comparison of the U. S. No. 1 variety with a commercial brand (Pioneer), planted April 22, 1930, at Castleford, Idaho*

[Data represent averages from 6 plots, each 90 feet long and 4 rows wide]

Variety	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
				Gross [1]	Indicated available [2]
	Pounds	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1	10,930	13.53	88.78	1,479	1,313
Commerical (Pioneer)	1,939	11.55	83.38	224	187
Difference	8,991	1.98	5.40	1,255	1,126
Odds of significance [3]	[4] 1,572:1	[4] 2,499:1	[4] 158:1	[4] 1,249:1	[4] 1,188:1

[1] Gross sugar per acre=yield per acre (in pounds) × sucrose percentage.

[2] Indicated-available sugar per acre=$\frac{\text{yield per acre (in pounds)} \times \text{proportional-value coefficient}}{100}$.

(Proportional-value coefficient=$\frac{\text{sucrose percentage} \times \text{coefficient of apparent purity}}{100}$).

[3] Determined by Student's Method (*1*, *2*); odds of 30 : 1 are considered significant.

[4] Odds of significance in favor of the U. S. No. 1 variety.

In obtaining these data, each plot was harvested and one 10-beet sample was taken at random for determining sucrose and purity. The determination of the coefficient of apparent purity was made in the standard manner (*4*), and the sucrose percentage was computed by multiplying the amount of sucrose in the juice by 0.95, to allow for an assumed marc of 5 per cent.

In 1931 a test was conducted at Castleford for the purpose of comparing the three seed increases of the original U. S. No. 1 selection with two standard commercial brands. The seed of the U. S. No. 1 variety was produced at Beaumont, Calif. (A); St. George, Utah (B); Las Cruces, N. Mex. (C); the seed of the commercial brands used, namely, Old Type (D)[13] and Pioneer (E),[13] was ordinary commercial seed. The plots were arranged in a Latin square so that the comparative data on yield, sucrose percentage, coefficient of apparent purity, and sugar per acre might be subjected to statistical analysis (*9*).

On April 11, 23 pounds of seed per acre was planted in plots, each $\frac{1}{96.6}$ of an acre in harvestable area and consisting of eight rows 22 inches apart, replicated five times in restricted random arrangement. The inner six rows of each plot were harvested October 19 on a normally competitive-beet basis,[14] and the data were computed on the basis of a 100 per cent stand of beets. Determinations of sucrose percentage and of the coefficient of apparent purity were made on three 20-beet samples of normally competitive beets from each plot. Sucrose was determined by the Sachs-Le Docte cold-water-digestion method. The coefficient of apparent purity was determined from the Brix reading of the expressed juice and the saccharimeter reading of sucrose in the clarified, undiluted juice by means of Schmitz's tables (*4*). The data (Table 2) have been analyzed according to accepted

[13] Produced by the Kleinwanzleben Zuckerfabrik, Kleinwanzleben, Germany.

[14] By "normally competitive beet" is meant a beet which has grown surrounded on all four sides by beets at approximately the right distance to conform to the requirements of the test. The value for weight per beet has been computed from the data from the competitive-beet samples, and this value multiplied by the appropriate number of beets per acre has given the value for yield in terms of 100 per cent stand for beets under the conditions of the experiment.

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statistical methods, and the value of z has been used as a convenient measure of the significance of the test for the attribute measured. In all cases in which the value of z equaled or exceeded either the 5 per cent or the 1 per cent point as given in Fisher's tables (*9*), the standard errors of the means have been computed in order to determine the difference required for significance.

TABLE 2.—*Comparison of three increases of the U. S. No. 1 variety with two commercial brands, planted April 11, 1931, at Castleford, Idaho*

[Data represent averages of five plots, each 1/66.6 of an acre in area and consisting of the six inner 22-inch rows of the original plot]

Variety	Yield		Sucrose [1]	Coefficient of apparent purity [2]	Sugar production [3]			
					Per plot		Per acre	
	Per plot	Per acre			Gross	Indicated available	Gross	Indicated available
U. S. No. 1 increase from—	*Pounds*	*Tons*	*Per cent*		*Pounds*	*Pounds*	*Pounds*	*Pounds*
Beaumont, Calif.	350.78	16.943	19.16	92.62	67.16	62.21	6,488	6,009
St. George, Utah	337.48	16.300	19.24	92.26	64.92	59.91	6,271	5,787
Las Cruces, N. Mex.	373.92	18.060	18.56	92.62	69.40	63.97	6,675	6,179
Average	354.06	17.101	18.99	92.50	67.16	62.03	6,478	5,991
Commercial:								
Old Type	190.38	9.195	18.62	91.70	35.45	32.47	3,424	3,137
Pioneer	204.18	9.862	19.10	92.06	39.16	36.13	3,783	3,490
Average	197.28	9.528	18.86	91.88	37.30	34.30	3,603	3,313
Difference	156.78	7.573	.13	.62	29.86	27.73	2,875	2,678
z [4]	1.6956	1.6956	[5] .3418	([6])	1.7711	1.7975	1.7711	1.7975
Standard error	35.22	1.701	--------	--------	6.2449	5.6781	603.7	547.8
Standard error of mean	15.752	.761	--------	--------	2.7929	2.5394	270	245
Standard error of difference	22.273	1.076	--------	--------	3.9492	3.5907	382	346
Difference required for significance	44.55	2.152	--------	--------	7.8984	7.1814	764	692

[1] Determined on three 20-beet samples of normally competitive beets per plot.
[2] Determined by direct reading of the Brix of the expressed juice and direct polariscopic determination of sucrose in the clarified, undiluted juice.
[3] Obtained by averaging of individual plot values; hence it differs slightly from product of the means given in this table.
[4] z=one-half the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z=0.5907; 1 per cent point=0.8443.
[5] Difference found was not significant by z test.
[6] Variance assignable to error was greater than variance assignable to effect of variety.

There were no significant differences in yield among the three seed increases of the U. S. No. 1 variety nor between the two commercial brands used for comparison. Each of the U. S. No. 1 seed increases, however, showed a much larger yield per plot than did either of the commercial brands, and there was a significant difference between the average yield of the U. S. No. 1 lots and the average yield of the commercial brands.

In sucrose percentage the results were not significant according to the z test. For the coefficient of apparent purity no significant differences were obtained, as the variance due to error was greater than that due to the effect of variety.

In sugar production no significant differences were found among the three U. S. No. 1 seed lots nor between the two commercial brands. In both gross and indicated-available sugar, however, the average of

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the U. S. No. 1 lots was significantly greater than the average of the commercial brands.

The test as a whole indicates that there were no significant differences among the three seed increases of the U. S. No. 1 variety and that each of these showed marked superiority to the two commercial brands used for comparison.

Counts of plants affected with "obvious[15] curly top" (Table 3) show no large differences among the three seed increases of the U. S. No. 1 variety, regardless of whether the readings were made early or late in the season. On each of the dates when readings were made, except the first date, the average percentage of obvious curly top for each of the three U. S. No. 1 lots was strikingly lower than that of either of the commercial brands. This is entirely consistent with the results given later for the grower-test plantings and the comparative-development studies.

TABLE 3.—*Percentage*[1] *of plants showing obvious curly top in each of three seed increases of the U. S. No. 1 variety as compared with that in two commercial brands, planted April 11, 1931, at Castleford, Idaho*

Variety	Percentage of plants showing obvious curly top on—					
	June 20	July 1	July 14	July 31	Aug. 11	Aug. 28
U. S. No. 1 increase from—						
Beaumont, Calif.	3.0	8.5	24.2	41.0	54.0	45.8
St. George, Utah	2.2	11.1	24.8	45.4	56.2	44.4
Las Cruces, N. Mex.	2.2	11.6	24.6	38.6	58.0	37.8
Commercial:						
Old Type	8.4	25.4	56.2	87.4	93.2	98.2
Pioneer	3.0	22.0	51.8	84.4	92.8	99.2

[1] Counts were made on all the beets in the center two rows of each plot; each reading is an average of 5 plots.

TEST AT TWIN FALLS

A companion test to the one conducted at Castleford—an area where severe outbreaks of curly top prevail—was undertaken at Twin Falls—an area in which curly-top outbreaks are not usually so severe—in order to compare the behavior of the three increases of the U. S. No. 1 variety with that of the two commercial brands used as checks. The planting plan used at Castleford was followed.

Twenty-three pounds of seed per acre was planted April 16 in plots, each one two-hundred-and-fourth of an acre in harvestable area and consisting of four rows, 20 inches apart, replicated five times in restricted random arrangement. The two center rows of each plot were harvested November 6 on a normally competitive-beet basis, and the data were computed on the basis of a 100 per cent stand. Determinations of sucrose percentage and coefficient of apparent purity were made on three 20-beet samples of normally competitive beets from each plot, in the manner previously described.

The data presented in Table 4 show that in yield per plot the results are not significant according to the z test. There were no large differences in yield between the U. S. No. 1 variety and the two commercial brands used as checks. Likewise there were no large differences in

[15] The term "obvious curly top" signifies that degree of curly-top reaction by which the disease can be detected in a rapid examination of the foliage as a whole and which does not require a close examination of the inner leaves. The conception of what constitutes obvious curly top might vary with different workers, but as all these counts were made by one person (Lowe) the records are closely comparable.

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yield among the three lots of the U. S. No. 1 variety, nor were the commercial brands appreciably different from each other. In sucrose percentage the results are not significant according to the z test. Aside from the lower sucrose percentage for the St. George seed increase, which must be considered, according to the z test, as a chance occurrence, the average sucrose percentage of the three lots of the U. S. No. 1 variety was 18.29, as compared with 18.47 for the commercial brands, both values being commercially acceptable.

TABLE 4.—*Comparison of the U. S. No. 1 variety with two commercial brands, planted April 16, 1931, at Twin Falls, Idaho*

[Data represent averages from five plots, each 1/204 of an acre in area and consisting of the two inner 20-inch rows of the original plot]

Variety	Yield		Sucrose	Coefficient of apparent purity	Sugar production [1]			
					Per plot		Per acre	
	Per plot	Per acre			Gross	Indicated-available	Gross	Indicated-available
U. S. No. 1 increase from—	*Pounds*	*Tons*	*Per cent*		*Pounds*	*Pounds*	*Pounds*	*Pounds*
Beaumont, Calif.	186.36	19.009	18.42	83.58	34.35	28.73	7,007	5,861
St. George, Utah	205.30	20.941	17.82	83.44	36.56	30.55	7,458	6,232
Las Cruces, N. Mex.	202.22	20.626	18.62	83.24	37.54	31.23	7,658	6,371
Commercial:								
Old Type	191.24	19.506	18.44	83.38	35.22	29.37	7,185	5,991
Pioneer	178.94	18.252	18.50	83.66	33.05	27.65	6,742	5,641
z [2]	[3].0807	[3].0807	[3].0575	([4])	[3].1889	[3].1725	[3].1889	[3].1725

[1] Obtained by averaging individual plot values; hence differing slightly from product of the means given in this table.
[2] z=one-half the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z=0.5907; 1 per cent point for z=0.8443.
[3] Difference found was not significant by z test.
[4] Variance assignable to error was greater than variance assignable to effect of variety.

For the coefficient of apparent purity, no reliable differences were obtained, inasmuch as the variance due to error was greater than that due to effect of variety.

In pounds of sugar per acre, the differences, according to the z test, are not significant. On comparing the three seed lots of the U. S. No. 1 variety among themselves, no appreciably large difference was found. In gross and indicated-available sugar an appreciably large difference was found between the Las Cruces seed increase of the U. S. No. 1 variety and the Pioneer commercial brand. Although this difference exceeds the amount required for significance, it must, according to the z test, be considered a chance occurrence.

Counts made of plants affected with obvious curly top (Table 5) show that for the period during which the observations were made the percentage of affected plants was relatively small. In each case the number of plants affected was less in the U. S. No. 1 variety than in the commercial brands used as checks.

This test as a whole indicates that under relatively light outbreaks of curly top the U. S. No. 1 variety approached in yields and in other attributes the two standard commercial brands with which it was compared.

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TABLE 5.—*Percentage* [1] *of plants showing obvious curly top in each of the three seed increases of the U. S. No. 1 variety as compared with two commercial brands, planted April 16, 1931, at Twin Falls, Idaho*

Variety	Percentage of plants showing obvious curly top on—			
	June 29	July 13	July 28	Aug. 15
U. S. No. 1 increase from—				
Beaumont, Calif.	3.0	9.2	13.0	21.6
St. George, Utah	2.2	8.6	16.6	24.4
Las Cruces, N. Mex.	2.0	10.2	16.8	26.4
Commercial:				
Old Type	5.9	25.8	50.4	70.0
Pioneer	7.6	22.2	45.0	62.6

[1] Counts were made on all the beets in the center 2 rows of each plot; each reading is an average of 5 plots

GROWER-TEST PLANTINGS

In 1931 grower-test plantings were made throughout the affected sugar-beet areas of Idaho. The season was characterized by a serious outbreak of curly top. The amount of damage resulting from curly top each season from 1927 to 1931, inclusive, is shown in Table 6, in which comparative data are given on acreages and average yields in the Jerome, Twin Falls, and Burley-Paul areas. These data indicate that the tests of 1930, described in the preceding section, were conducted under conditions that probably represent a maximum of curly-top exposure for the Idaho beet-growing district and that those of 1931 were made under conditions of a moderately severe curly-top epidemic. Although the influx of beet leaf hoppers began at approximately the same date in 1931 as in 1930 and continued over a considerable period,[16] the number of insects was apparently smaller.

TABLE 6.—*Acreages and average yields for the Twin Falls, Jerome, and Burley-Paul, Idaho, areas from 1927 to 1931*

Year	Number of acres						Average yield per acre based on—					
	Thinned			Harvested			Acres harvested			Acres thinned		
	Jerome	Twin Falls	Burley-Paul	Jerome	Twin Falls	Burley-Paul	Jerome	Twin Falls	Burley-Paul	Jerome	Twin Falls	Burley-Paul
							Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1927 [a]	1,986	4,966	3,945	1,479.51	4,887.12	3,533	11.95	16.35	14.46	8.90	15.44	12.95
1928 [b]	[c] 206	[c] 152	[c] 1,633	61.81	110.66	1,544.5	4.63	8.39	11.46	1.39	6.11	10.84
1929 [a]	2,009	7,004	4,849	1,251.58	6,307.85	4,795.5	9.92	12.99	12.68	6.18	11.70	12.54
1930 [b]	1,171	3,764	6,822	781.66	2,221.24	6,329	7.13	8.70	9.69	4.76	5.14	8.99
1931 [b]	317.4	1,125.4	3,198	270.50	1,061.50	2,958	8.92	7.13	9.35	7.61	6.72	8.65

[a] Curly top not serious.
[b] Curly top serious.
[c] The drop in acreage in 1928 was due primarily to the effect of the forecast by the Bureau of Entomology that the numbers of leaf hoppers in the breeding grounds indicated decidedly unfavorable prospects for the beet crop.

[16] P. N. Annand, entomologist in charge of the sugar-beet insect field laboratory at Twin Falls, has furnished the following statement: "The influx began on May 24, the same date as in 1930, and continued over a period of five weeks. The flight was smaller than in 1930 as indicated by the numbers of leaf hoppers per beet and by numbers intercepted by flight traps."

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In the grower-test plantings of 1931, a special effort was made to select localities where different degrees of curly-top exposure might be expected. Nineteen plantings were made in the sugar-beet area from Filer, on the west, to McCammon, on the east, as follows: Two fields at Filer, 2 at Twin Falls, 3 at Jerome, 2 at Kimberley, 2 at Hansen, 2 at Murtaugh, and 1 each at Burley, Paul, Rupert, Aberdeen, Fort Hall, and McCammon.[17] The planting at Fort Hall and one of those at Jerome were lost shortly after they were made, so that this report concerns itself with 17 plantings, as listed in Table 7.

In order to test the performance of the U. S. No. 1 variety under average farm conditions, an extensive series of plantings was made of the first multiplication of the seed used in the 1930 tests. Representative farms were chosen where, in the opinion of factory managers and agriculturists [18] consulted, the crop would receive proper handling. These farms were so distributed as to give a representative cross section of the whole beet acreage in Idaho, where curly top is regularly a serious factor. The plan used was to plant the seed of the U. S. No. 1 variety and that of a commercial brand in alternate strips 16 rows wide. The number of such strips varied from two to four sets for each field, depending on the size of the field and the supply of the seed. In every case, as nearly as could be judged at planting time, these strips were so located that neither the U. S. No. 1 nor its commercial check was unfavorably placed; all the plantings were made under the supervision of the writers, and the boundaries of the plots were carefully staked and recorded to prevent errors when the plots were harvested. The areas involved in these comparisons were approximately 1 acre for the U. S. No. 1 variety and a similar area for the commercial check. During the growing season, inspection trips were made at intervals of two weeks to observe closely the differences in these 17 grower-test plantings in regard to growth, degree of curly-top infestation, and progressive development of the U. S. No. 1 variety and the commercial brand. By doing this, it was possible to insure identical treatment of the comparison strips in regard to timeliness of thinning, uniform irrigation, and other cultural operations.

At the time of planting it was noticed that the seed balls of the U. S. No. 1 variety were, on an average, larger than the seed balls of the commercial brand. This difference in size necessitated the adjustment of the drill to insure that approximately the same weight of both lots of seed was used in the comparison strips. When viewed along the row, the seedlings of the U. S. No. 1 variety appeared slightly darker than the seedlings of the commercial brands. Close examination showed that the foliage of the U. S. No. 1 variety was a darker green than that of the commercial brands and that a fairly high percentage of the U. S. No. 1 plants had red coloration in the petioles.

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[17] Acknowledgment is made of the helpful cooperation given by the following farmers in whose fields the tests were conducted: Martin Meier and H. F. McKay, of Twin Falls; W. H. Newman and S. D. Perrine, of Kimberley; J. Mason and V. Naylor, of Hansen; J. Priest and J. Sackett, of Filer; R. C. May, of Rupert; D. B. Hardin, of Paul; J. H. Bodily, of Burley; D. F. Turner and Francis Johnson, of Murtaugh; E. J. Netz, W. H. Stoddard, and M. Reich, of Jerome; W. R. Christensen, of McCammon; G. Becker, of Aberdeen; and S. A. Dunn, of Fort Hall. Acknowledgment is also due the Amalgamated Sugar Co. and the Utah-Idaho Sugar Co. for advice and assistance in securing the test fields in their respective operating districts.

[18] Acknowledgment is made of the assistance and continued interest throughout these experiments of A. R. Hagar, R. C. May, and R. H. Tallman, of the Amalgamated Sugar Co., and W. Y. Cannon, of the Utah-Idaho Sugar Co.

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In the various grower-test plantings no consistent differences in relative stand or size were noted, prior to thinning, between the U. S. No. 1 plots and the adjoining plots planted with the commercial brand. After thinning, the plants in the comparison strips continued growth without noticeable differences in stand or size until after the leaf-hopper attack began. In most cases the beet leaf hoppers appeared in the fields during the latter part of May, and curly-top symptoms became evident the first week in June, little damage appearing until after June 20. At that time the beet fields (located under the Twin Falls irrigation system) began to show rather pronounced curly-top damage in the commercial strips and only slight damage in the adjacent strips planted with the U. S. No. 1 variety. The progressive development of the disease is shown in Table 7, in which the field records for obvious curly top are arranged according to districts. These detailed records are based upon readings obtained from a large number of rows selected at random. Each reading given is an average based upon at least 10 sets of 100 consecutive beet plants in each comparison strip. The table shows also the obvious curly top occurring in portions of the rows selected at random. In all the grower-test plantings the counts were taken at intervals of approximately two weeks throughout the season, beginning June 17 to 26, and show that curly top became severe before the close of August. At the close of the season all but 1 of the commercial plots in the 17 test fields showed nearly 100 per cent obvious curly top, the exception (field 16) showing 50 per cent. The U. S. No. 1 variety, on the other hand, had shown in many cases a tendency apparently to recover from the disease; in 14 of the fields the obvious curly top ranged from 37 to 72 per cent, and 3 of the fields (16, 5, and 9) showed only 19, 27, and 24 per cent of curly top, respectively. A detailed account of these results is given in Table 7.

TABLE 7.—*Percentage* [1] *of plants showing obvious curly top in the grower-test plantings of the U. S. No. 1 variety and commercial brands in Idaho in 1931*

[Data represent averages of a minimum of 10 counts of 100 beets for each planting]

Area and locality	Field No.	Variety [2]	Percentage of plants showing obvious curly top on—									
			June 17–26	July 2–8	July 17–24	Aug. 3–7	Aug. 17–22	Aug. 31 to Sept. 4	Sept. 14–18	Sept. 25	Oct. 10	
											Foliage mildly affected	Foliage severely affected
Twin Falls area:												
Twin Falls	1	U. S. No. 1	7	16	18	24	54	39	35	37	30	7
		Commercial	17	55	61	82	100	100	95	96	42	54
	2	U. S. No. 1	12	13	28	30	66	63	63	61	39	21
		Commercial	27	48	57	80	97	100	95	98	26	72
Kimberley	3	U. S. No. 1	9	19	28	42	72	60	61	72	57	15
		Commercial	20	65	86	98	100	100	100	97	25	72
	4	U. S. No. 1	19	21	42	57	74	59	63	------	-------	-------
		Commercial	51	69	91	100	100	100	100	------	-------	-------

[1] The rows in which the counts were made were selected at random for each comparison-strip planting.
[2] In the grower-test plantings the following commercial brands were used: Fields 1, 2, 6, and 13, Old Type; field 16, Pioneer, both brands of the Zuckerfabrik Kleinwanzleben; in fields 7, 8, 11, 12, and 15, seed from the same firm was used, but the particular brand was not available from factory records; fields 3, 5, and 10, Elite (Schreiber & Son); fields 4, 14, and 17, Elite (C. Braune); field 9, F. F. (E. Frederiksen).

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TABLE 7.—*Percentage of plants showing obvious curly top in the grower-test plantings of the U. S. No. 1 variety and commercial brands in Idaho in 1931*—Con.

Area and locality	Field No.	Variety	Percentage of plants showing obvious curly top on—									
			June 17–26	July 2–8	July 17–24	Aug. 3–7	Aug. 17–22	Aug. 31 to Sept. 4	Sept. 14–18	Sept. 25	Oct. 10	
											Foliage mildly affected	Foliage severely affected
Twin Falls area—Con.												
Hansen	5	U. S. No. 1	7	11	30	39	69	53	68	26	21	6
		Commercial	27	44	82	97	100	100	100	98	53	47
	6	U. S. No. 1	8	9	22	27	60	48	52	39	28	10
		Commercial	24	39	71	92	100	100	97	98	42	56
Filer	7	U. S. No. 1	5	5	7	20	46	38	31	40	32	8
		Commercial	27	25	39	77	89	94	88	96	39	57
	8	U. S. No. 1	3	13	28	46	76	60	54	33	22	11
		Commercial	17	33	74	96	100	100	100	99	48	51
Burley area:												
Rupert	9	U. S. No. 1	3	7	10	13	21	27	23	25	19	5
		Commercial	11	28	36	56	91	100	90	94	59	36
Paul	10	U. S. No. 1	3	13	31	30	42	50	52	47	38	9
		Commercial	7	26	60	83	96	100	100	96	61	35
Burley	11	U. S. No. 1	------	11	21	31	54	51	39	49	33	16
		Commercial	------	21	46	70	100	100	92	97	30	66
Murtaugh	12	U. S. No. 1	12	19	36	50	57	62	64	51	37	14
		Commercial	38	59	84	100	100	100	100	99	18	81
	13	U. S. No. 1	7	11	20	40	54	51	54	49	31	18
		Commercial	26	43	68	93	100	100	100	98	23	75
Jerome area:												
Jerome	14	U. S. No. 1	2	11	22	40	66	60	48	59	38	21
		Commercial	5	21	44	80	100	100	93	96	29	67
	15	U. S. No. 1	2	4	14	35	58	54	56	59	40	19
		Commercial	3	10	34	79	100	100	89	89	35	54
Eastern area:												
McCammon	16	U. S. No. 1	0	3	7	12	14	22	24	19	14	5
		Commercial	0	7	19	27	46	59	61	50	27	23
Aberdeen	17	U. S. No. 1	4	17	32	53	42	51	42	38	27	11
		Commercial	9	29	68	85	92	100	93	94	50	44
Average	------	U. S. No. 1	6.4	11.9	23.2	34.6	54.4	49.8	48.6	43.8	31.6	12.2
		Commercial	19.2	36.5	59.9	82.0	94.8	97.2	93.7	93.3	37.8	55.5

In taking the last count of beets affected with obvious curly top just before harvest, the effects of the disease on the foliage were classified as either mild or severe. The commercial brands used as checks usually showed a greater proportion of severe cases than mild ones. In the U. S. No. 1 variety, however, the mild type of disease constituted nearly three-fourths of the obvious curly top. In the commercial brands the percentages of severe curly top ranged from 23 to 81, whereas in the resistant variety the range was 5 to 21 per cent.

The data in Table 7 show that in all the fields but one the disease in the commercial beets had practically reached the maximum of incidence by the last of August and that throughout the season the U. S. No. 1 variety showed a marked degree of resistance to curly-top infection. In view of the severity of the disease in these areas, it is obvious that the season afforded for nearly all fields a fairly severe test of the U. S. No. 1 variety. (Fig. 5.)

The harvest results of the 17 grower-test plantings are given in Table 8. The methods used in securing the data were as follows: From each strip constituting a part of the grower-test planting, twenty 20-beet samples of normally competitive beets were selected at random. These beets were put in moisture-proof sacks and taken to the laboratory, where they were washed, weighed, and analyzed.

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Determinations of sucrose percentage and of the coefficient of apparent purity were made separately for each 20-beet sample of normally competitive beets in the manner previously described.

FIGURE 5.—Grower-test planting on the Newman farm, at Kimberley, near Twin Falls, Idaho, showing the U. S. No. 1 variety at the right and a commercial brand (Schreiber & Son's Elite) at the left. Planted March 11, 1931; photographed July 26, 1931

TABLE 8.—*Results of grower-test plantings of the U. S. No. 1 variety and commercial brands in Idaho in 1931*

Area and locality	Field No.	Planting date	Yield per acre [1]			Sucrose			Coefficient of apparent purity		
			U. S. No. 1	Commercial	Difference	U. S. No. 1	Commercial	Difference [2]	U. S. No. 1	Commercial	Difference [2]
Twin Falls area:			*Tons*	*Tons*	*Tons*	*Per ct.*	*Per ct.*	*Per ct.*			
Twin Falls	1	Mar. 23	17.906	13.038	4.868	18.35	18.38	−0.03	94.98	95.69	−0.71
	2	Apr. 27	21.424	14.694	6.730	16.84	16.89	−.05	92.22	91.48	.74
Kimberley	3	Mar. 11	12.741	7.282	5.459	18.58	17.90	.68	92.13	90.69	1.44
	4	Mar. 20	10.062	6.527	3.535	16.30	16.41	−.11	97.69	95.26	2.43
Hansen	5	Apr. 4	8.115	4.257	3.858	18.18	18.11	.07	93.32	91.87	1.45
	6	Mar. 23	8.209	5.749	2.460	18.42	18.37	.05	94.41	93.57	.84
Filer	7	Apr. 3	17.828	14.244	3.584	19.20	19.20	0	93.85	94.16	−.31
	8	do	12.071	5.697	6.374	19.06	18.23	.83	94.18	90.90	3.28
Burley area:											
Rupert	9	Apr. 4	18.814	14.208	4.606	16.98	17.52	−.54	94.17	95.60	−1.43
Paul	10	Apr. 10	24.417	17.410	7.007	16.19	16.97	−.78	94.90	95.00	−.10
Burley	11	do	11.728	7.331	4.397	17.83	17.75	.08	96.35	96.69	−.34
Murtaugh	12	Apr. 4	11.627	6.766	4.861	19.19	18.34	.85	94.96	93.11	1.85
	13	Apr. 3	10.941	8.331	2.610	18.84	18.49	.35	96.25	95.92	.33
Jerome area:											
Jerome	14	Mar. 30	16.668	11.731	4.937	17.84	17.48	.36	93.97	94.21	−.24
	15	Apr. 8	14.361	11.015	3.346	18.04	18.37	−.33	94.71	94.12	.59
Eastern area:											
McCammon	16	Apr. 28	11.385	9.085	2.300	18.37	18.83	−.46	92.10	90.77	1.33
Aberdeen	17	Apr. 21	14.927	6.707	8.220	18.16	17.65	.51	90.13	88.89	1.24
Average			14.307	9.651	[3] 4.656	18.02	17.93	[4] .09	94.14	93.41	[4] .73

[1] Yield values were obtained from normally competitive beets and were computed on the basis of a 100 per cent stand.
[2] When the commercial exceeds U. S. No. 1, a minus sign is used.
[3] Odds 9999 to 1 that difference as great as shown was not due to chance alone (*2*).
[4] Odds less than 30 to 1 that difference as great as shown was not due to chance alone.

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TABLE 8.—*Results of grower-test plantings of the U. S. No. 1 variety and commercial brands in Idaho in 1931*—Continued

Area and locality	Field No.	Planting date	Sugar per acre					
			Gross			Indicated available		
			U. S. No. 1.	Commercial	Difference	U. S. No. 1	Commercial	Difference
			Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Twin Falls area:								
Twin Falls	1	Mar. 23	6,572	4,793	1,779	6,242	4,586	1,656
	2	Apr. 27	7,216	4,964	2,252	6,654	4,541	2,113
Kimberley	3	Mar. 11	4,735	2,607	2,128	4,362	2,364	1,998
	4	Mar. 20	3,280	2,142	1,138	3,204	2,041	1,163
Hansen	5	Apr. 4	2,951	1,542	1,409	2,749	1,417	1,332
	6	Mar. 23	3,024	2,112	912	2,855	1,977	878
Filer	7	Apr. 3	6,846	5,470	1,376	6,425	5,151	1,274
	8	do	4,602	2,077	2,525	4,334	1,888	2,446
Burley area:								
Rupert	9	Apr. 4	6,389	4,979	1,410	6,017	4,759	1,258
Paul	10	Apr. 10	7,906	5,909	1,997	7,503	5,614	1,889
Burley	11	do	4,182	2,603	1,579	4,030	2,516	1,514
Murtaugh	12	Apr. 4	4,462	2,482	1,980	4,238	2,311	1,927
	13	Apr. 3	4,123	3,073	1,050	3,968	2,948	1,020
Jerome area:								
Jerome	14	Mar. 30	5,947	4,101	1,846	5,589	3,864	1,725
	15	Apr. 8	5,182	4,047	1,135	4,908	3,809	1,099
Eastern area:								
McCammon	16	Apr. 28	4,183	3,422	761	3,853	3,106	747
Aberdeen	17	Apr. 21	5,422	2,368	3,054	4,886	2,105	2,781
Average			[5] 5,119	[5] 3,452	[3] 1,667	[5] 4,813	[5] 3,235	[3] 1,578

[3] Odds 9999 to 1 that difference as great as shown was not due to chance alone (*2*).
[5] Obtained by averaging the sugar-per-acre values computed for the individual fields; hence it differs slightly from the product of the means given in this table.

The results from the 17 fields show that the U. S. No. 1 variety outyielded the commercial brand in every case. The difference in favor of the U. S. No. 1 variety was 2.3 tons per acre in the field (16) showing the lowest difference, which was the field where obvious curly top occurred in the lowest percentage. The average gain for all 17 fields was 4.66 tons per acre, a significant difference. The individual gains, as calculated by this method, ranged from 2.3 tons to 8.2 tons per acre. In seven fields the commercial brand showed the higher average sucrose percentage per beet, and in nine fields the U. S. No. 1 variety was the higher. In no case did the difference exceed 0.85, which was too small to be significant. Six fields showed a higher average coefficient of apparent purity per sample for the commercial beets, and 11 fields showed a higher average purity for the U. S. No. 1 variety. In no case did the difference exceed 3.28, and the average difference (0.73) was too small to be significant. In the calculated yield of sugar (pounds per acre) the U. S. No. 1 variety exceeded the commercial brand in every case. The difference in favor of the U. S. No. 1 variety was 761 pounds of gross sugar and 747 pounds of indicated-available sugar in the field (16) showing the lowest difference, which, as noted previously, was the field where the obvious curly top was the lowest. The average difference in favor of the U. S. No. 1 variety in all 17 fields was 1,667 pounds of gross sugar per acre and 1,578 pounds of indicated-available sugar. The individual differences ranged from 761 to 3,054 pounds of gross sugar per acre, and from 747 to 2,781 pounds of indicated-available sugar per acre.

It must be borne in mind that these yields in tons of beets and pounds of sugar produced are based on the average individual root

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weight for the contrasted types, resistant and nonresistant, and have been computed uniformly on a 100-per-cent-stand basis. Actual yields per acre were less, since stands were not perfect, but this consideration does not affect the relations shown by the differences, except, perhaps, to handicap the resistant variety.

The comparisons as made show the essential differences in weight and quality that may exist among beets growing under uniform conditions of competition. In such a consideration of the data, the influence of the stand factor as it might affect yield per acre is eliminated. The fact that the stand relations are eliminated influences the results obtainable by this method in those cases where some factor affects the stand in the check and tested plots differently. The curly-top disease, for instance, may and often does decrease the stand in the check more than it does that of a resistant variety. Obviously a decrease in stand due to the disease must be recognized as a part of the damage, and when this consideration is left out of the evaluation the resistant variety is to that extent handicapped. There are, however, certain practical advantages in the method. Extensive samples from the comparison strips may be taken in advance of the regular harvest, thereby affording a precise comparison as to sucrose percentage and coefficient of apparent purity and also some measure of yields, whereas it is often impossible to get satisfactory records of quality and yields at the time a whole field is harvested. It seems that under curly-top conditions a fairly representative value for actual yield per acre may be arrived at by applying the harvest-stand count to the data obtained from the normally competitive-beet samples.

In five of these tests the actual yields produced on measured areas planted to the two contrasted beet types were obtained as a check on the method employed. (Table 9.) The table gives the actual yields obtained from the resistant and nonresistant beets under the conditions of the particular field. These are compared with the yields computed from the individual beet weight as determined from the normally competitive-beet samples, assuming the stand to be 100 per cent.

TABLE 9.—*Yield computed on basis of 100 per cent stand of normally competitive beets as compared with actual yields from grower-test plantings in Idaho in 1931*

Locality	Field No.	Actual yield per acre				Yield per acre on basis of 100 per cent stand of normally competitive beets			
		U. S. No. 1	Commercial	Difference		U. S. No. 1	Commercial	Difference	
		Pounds	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Pounds*	*Pounds*	*Per cent*
McCammon	16	15,964	8,150	7,814	95.9	22,771	18,171	4,600	25.3
Rupert	9	30,300	20,200	10,100	50.0	37,629	28,416	9,213	32.4
Jerome	14	23,406	13,582	9,824	72.3	33,336	23,463	9,873	42.1
Kimberley	3	14,673	5,342	9,331	174.7	25,482	14,564	10,918	75.0
Twin Falls	2	28,396	14,223	14,173	99.6	42,849	29,389	13,460	45.8
Average	------	22,548	12,299	10,249	83.3	32,413	22,801	9,612	42.2

It will be noted that with the exception from the McCammon field, in which, irrespective of curly top, considerable stand variation occurred, the differences between the U. S. No. 1 variety and the

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commercial brand used as check, determined by the two methods, are of approximately the same magnitude.

From the actual yield data in Table 9 the superiority of the U. S. No. 1 variety over the commercial brand used as a check appears even more striking than is shown in Table 8. This was partly due to the difference in the actual stands. In every case the resistant type showed a high percentage of gain over the commercial brand. This percentage of gain is higher than that found when the root weights of the average individual of each type growing under normal competition conditions were used as the basis of comparison. In yield of beets, however, the difference between the U. S. No. 1 variety and the commercial brand as determined by the two methods was approximately the same. Although theoretically it might be expected that stand differences would be reflected in the yields and that usually there is considerable compensating for missing beets in the row, it is not certain that these factors operate under curly-top conditions. It seems likely that basing judgment as to varietal performance on an adequate number of normally competitive beets was reliable and probably more conservative than judgment based on actual yields which may be biased by extraneous influences on stand. The conclusions warranted from the two methods of determining yield are (1) that the average root size of sugar beets from the U. S. No. 1 seed, under such conditions as existed in this test, was greater than the root size of the beets grown from commercial seed, and (2) that a given area planted with U. S. No. 1 seed was shown to outyield a similar area planted with commercial seed.

COMPARATIVE DEVELOPMENT STUDIES

A study of the rate of development of the beet plant was undertaken at Twin Falls on both the U. S. No. 1 variety and a commercial brand (Rabbethge & Giesecke Old Type). On April 17 the seed stocks were planted, 28 pounds to the acre, in rows 20 inches apart, in two adjoining 40-row blocks. The blocks were approximately 270 feet long, and were separated by 3-foot alleyways into three 90-foot sections. Every other row was used for sampling, thus insuring a 1-row buffer between each sampling area. The samplings were made at weekly intervals from June 17 to October 7. (Table 10.) The readings for percentage of obvious curly top paralleled those obtained in the grower-test plantings. (Table 7.) The U. S. No. 1 variety showed uniformly less obvious curly top than the commercial brand. In growth of foliage the U. S. No. 1 variety showed a uniformly greater development from late June until harvest, the difference being greater at time of harvest than during the earlier stages of growth. The root weight of the commercial brand, however, increased more rapidly during the early part of the growing season; but this advantage was lost about mid August, when the root weight of the U. S. No. 1 variety approximately equaled that of the commercial brand. During September there was a marked tendency on the part of the U. S. No. 1 variety to show a greater relative growth rate than the commercial brand, an advantage it maintained up to the time of harvest. As calculated from the data of October 7 (25 ounces for the U. S. No. 1 root weight and 18.86 ounces for the root weight of the commercial brand), the yields were 20.42 tons and

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15.40 tons per acre, respectively, a difference of 5 tons in favor of the U. S. No. 1, which approximates closely the average difference (4.6 tons) as calculated for the grower-test plantings. In sucrose percentage there was a marked tendency for the commercial brand to show an advantage, although at harvest the differences became less pronounced. The quality of beets produced from the resistant variety (16.56 per cent sucrose as compared with 17.06 per cent from the commercial brand) was acceptable.

TABLE 10.—*Comparative development of the U. S. No. 1 variety and a commercial brand (Rabbethge & Giesecke Old Type) used at Twin Falls, Idaho, 1931*

Sampling date	Average weight of beets		Average weight of foliage		Average sucrose		Percentage of plants showing obvious curly top	
	U. S. No. 1	Commercial	U. S. No. 1	Commercial	U. S. No. 1	Commercial	U. S. No. 1	Commercial
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
June 17	0.50	1.35	2.40	2.85				
June 24	.85	1.95	5.30	4.80				
July 2	3.46	4.50	9.11	7.13			1.6	31.3
July 8	4.53	6.78	9.03	8.59			5.0	33.3
July 15	5.60	6.18	10.66	7.75			5.0	32.0
July 22	9.80	9.15	13.90	9.00			11.6	36.6
July 30	10 91	13.45	13.65	11.10	12.73	13.93	20.0	58.3
Aug. 6	13.10	13.16	14.55	9.43	13.33	14.73	18.0	70.0
Aug. 12	14.96	14.91	14.85	9.98	15.07	15.07	23.3	85.0
Aug. 19	19.38	19.51	15.68	13.38	13.53	14.60	36.5	86.5
Aug. 27	22.05	22.55	19.88	13.86	14.26	15.00	36.6	100.0
Sept. 2	25.50	21.41	23.03	14.28	13.86	15.26	21.7	95.0
Sept. 10	20.30	22.20	17.00	12.55	14.33	15.20	31.6	98.0
Sept. 16	25.30	18.20	20.30	10.51	15.13	15.20	36.6	98.0
Sept. 24	29.26	24.20	20.68	13.03	15.60	16.36	26.6	91.7
Sept. 30	26.41	19.88	22.86	11.35	16.03	17.10	15.0	95.0
Oct. 7	25.00	18.86	19.58	13.06	16.56	17.06	16.6	95.0

Although these results can not be assumed to have general applicability, since they involve only a single season and particular field conditions, the final readings are nevertheless consistent with the general trend of the results obtained in the other tests reported in this bulletin.

TESTS IN UTAH AND COLORADO [19]

INTENSIVE AGRONOMIC TESTS IN UTAH

In 1930 critical studies were begun in Utah on the U. S. No. 1 variety in order to test its resistance to curly top as compared with that of various commercial brands.

The first of these experiments were carried on in two ½-acre experimental plots on representative farms near Magna. This locality was chosen because curly-top epidemics had regularly occurred there for a number of years. The two experimental plots (Taylor field and Coon field) were about 4 miles apart. These fields were planted on April 8 and 9, respectively, somewhat later than the earliest commercial plantings in this district, in order that the plants might be comparatively small at the time of the early leaf-hopper invasion and therefore exposed to relatively severe injury from curly top.

[19] Contributed by F. V. Owen, F. A. Abegg, and Wesley Keller. The work in Utah was carried on with the cooperation of the Utah Agricultural Experiment Station. The writers acknowledge many helpful suggestions from Eubanks Carsner.

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TESTS AT TAYLOR FIELD

At the Taylor field, the U. S. No. 1 variety was replicated seven times in single-row plots 50 feet long. There were also two rows 350 feet long used for an additional test. A commercial brand (Schreiber S. K. W.) [20] was used as a check.

The injury from curly top in this field was only moderate, although considerable numbers of beet leaf hoppers were observed. There was no artificial inoculation of any kind, so that the disease produced was entirely dependent upon the natural leaf-hopper infestation. Evidently the virus carried by these insects was attenuated or low in virulence, for until the first part of September no marked contrast was observed between the plots planted with the resistant variety and those planted with the commercial brand. At this time the U. S. No. 1 variety was darker green in color and appeared to be more vigorous. At harvest time (October 16) the commercial plots had changed to a very pale yellow, while the U. S. No. 1 plots still appeared green. The results from the harvest of the replicated plots are given in Table 11.

TABLE 11.—*Comparison of the U. S. No. 1 variety with a commercial brand, planted April 8, 1930, in Taylor field, near Magna, Utah*

[Data represent averages from seven single-row plots, each 50 feet long]

Variety	Yield per acre	Sucrose [1]	Gross sugar per acre [2]
	Tons	*Per cent*	*Pounds*
U. S. No. 1	19.5	17.7	6,903
Commercial (Schreiber S. K. W.)	14.6	18.3	5,344
Difference	4.9	−.6	1,559

[1] Determined on a 10-beet sample from each plot.
[2] Gross sugar per acre was computed by multiplying the average yield in pounds by the average sucrose percentage.

The difference in yield of practically 5 tons per acre in favor of the U. S. No. 1 variety (nearly four times as great as its standard deviation) was undoubtedly significant. There was a significant difference (0.6 per cent) in sucrose percentage in favor of the commercial brand. However, larger beets were used for analysis from the U. S. No. 1 variety than from the commercial brand, and there is a well-known tendency for small sugar beets to be slightly higher than large ones in sucrose percentage. In total yield of sugar per acre the U. S. No. 1 variety showed a very decided increase over the commercial brand.

The results from the additional test of two long rows were of the same order. The yield for the U. S. No. 1 variety was 23.7 tons per acre, as compared with 20.3 tons for the commercial brand, and the sucrose percentage for the U. S. No. 1 variety was 17.5 per cent, as compared with 18.2 per cent for the commercial brand.

[20] Produced by Schreiber & Son, Nordhausen, Germany.

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TESTS AT COON FIELD

At the Coon field, the U. S. No. 1 variety was replicated four times. Each plot consisted of one row 50 feet long. Artificial measures were employed to induce a severe curly-top epidemic in this experimental field. A row of diseased mother beets infected with curly top the previous season was planted along one side of the field in order to supply a source of virulent virus for the beet leaf hoppers coming in from the desert breeding areas. The migrating insects in this area are usually nonviruliferous or else carry only an attenuated virus. If a source of virulent virus is in a field some of the incoming leaf hoppers will take up the virus by feeding on the diseased plants and transmit it to other plants, thus initiating an epidemic of the disease. The virulent virus was also introduced into this field by means of beet leaf hoppers that had been produced on diseased plants. These insects were obtained from the laboratory of the Bureau of Entomology at Twin Falls, Idaho. On June 3 the viruliferous leaf hoppers were caged two to a plant on one-half of each plot (25 feet) in order to give the plants in certain belts across the field a nearly uniform and very severe exposure to the disease.

Previous to this date a general migration of beet leaf hoppers into the Magna district had occurred, resulting in an infestation of both the Coon and the Taylor fields. Two counts in each field on June 3 indicated about 22 leaf hoppers per 100 feet of row in the Coon field and 32 per 100 feet in the Taylor field. More counts probably would have indicated about equal infestations in the two fields.

The success of the artificial inoculation measures used in the Coon field was noted by general observations and also by careful counts of the amount of curly top at intervals during the season. It was apparent that there was much more injury from the disease at the Coon field than at the Taylor field. The disease in the latter field was so mild that, as previously noted, no marked difference between the resistant variety and commercial brand appeared until the first part of September. In the Coon field the belts inoculated by caging were significantly more affected than the belts not so inoculated. This fact was better demonstrated by the extent of the yield reductions than by percentage of diseased plants on any particular date. That the rate of development of the epidemics differed in the two fields, doubtless because the virulent virus had been artificially introduced into the Coon field, is shown by comparing the amount of curly top in the commercial brand used as a check in the naturally infested portion of the Coon field with the amount in the commercial brand in the Taylor field during the same periods. On June 24, the Taylor field showed 3 per cent of the plants diseased, whereas the Coon field showed 63 per cent diseased. On July 17, the Taylor field showed 20 per cent diseased, whereas the Coon field showed 95 per cent diseased.

The harvest results at the Coon field are summarized in Table 12. The chemical analyses reported are based on a composite sample of five beets per plot.

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TABLE 12.—*Comparison of the U. S. No. 1 variety with a commercial brand, planted April 9, 1930, in Coon field, near Magna, Utah*

[Data represent averages from four single-row plots, each 25 feet long]

PLANTS INOCULATED BY NATURAL INFESTATION

Variety	Number per 100 feet		Stand loss	Yield per acre	Sucrose	Gross sugar per acre [1]
	June 20	Oct. 25				
			Per cent	*Tons*	*Per cent*	*Pounds*
U. S. No. 1	104	98	5.8	17.1	16.20	5,540
Commercial (Schreiber S. K. W.)	81	69	14.8	7.1	16.34	2,320
Difference	23	29	----------	10.0	−.14	3,220
PLANTS INOCULATED BY NATURAL INFESTATION AND BY CAGING LEAF HOPPERS						
U. S. No. 1	91	86	5.5	7.6	----------	----------
Commercial (Schreiber S. K. W.)	75	51	32	2.5	----------	----------
Difference	16	35	----------	5.1	----------	----------

[1] Gross sugar per acre was determined by multiplying the average yield in pounds by the average sucrose percentage.

These results show that in the belts exposed only to natural infestation, the U. S. No. 1 variety exceeded the commercial brand in yield by 10 tons per acre. The percentage of sucrose was practically the same in the resistant variety as in the commercial brand. The calculated yield of sugar per acre was 139 per cent greater for the U. S. No. 1 variety than for the commercial brand. In the belts where, in addition to the natural infestation, viruliferous beet leaf hoppers were caged on the plants, the yield from the U. S. No. 1 variety, although it had been greatly reduced by the drastic exposure, was three times the yield from the commercial brand.

GROWER-TEST PLANTINGS

In 1931 an extensive program was outlined whereby U. S. No. 1 seed could be given actual field trials [21] in the beet-growing areas of Utah and on the western slope of Colorado. Generally districts were selected where there had previously been severe outbreaks of curly top. Some districts reporting little damage were included, however, because it was thought desirable to know the merits of U. S. No. 1 seed under conditions of relative freedom from curly top as well as under conditions of severe disease.

In order to evaluate the resistant variety under normal farm conditions, localities were chosen where the beets would have good cultural care in productive soil and where the grower would take a personal interest in the problem.

[21] Special acknowledgment should be made to the growers who made the tests possible and also to the sugar companies for their active and sympathetic cooperation. The Utah-Idaho Sugar Co., the Amalgamated Sugar Co., and the Gunnison Sugar Co. cooperated in securing the Utah plantings. The plantings in Colorado were made in cooperation with the Holly Sugar Co.

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The plantings were made as early as the season permitted. In practically every case the seed was planted as soon as the farmer was ready.[22] Care was taken to plant sufficient seed to insure good stands, and in most of the plots the stands proved satisfactory.

In each field as many replications were made as seemed feasible. Generally blocks of 16 rows were planted alternately to commercial seed and to the U. S. No. 1 variety. The number of blocks of the resistant variety ranged from 2 to 4. Some plantings were larger than others, but an attempt was made to plant about 1 acre to U. S. No. 1 seed at each place.

Each planting was inspected about once a month throughout the season. During the early period of growth careful observations were made to detect the presence of beet leaf hoppers and the first signs of curly top. Numerous curly-top counts were made, especially while the plants were young, to determine the progress of the disease. As the plants advanced in age a simple count of those diseased seemed entirely inadequate. The only satisfactory method of comparing them was to classify each plant according to the degree of curly top. This method, however, was found to be very time-consuming and impracticable for large-scale operations. In order not to confuse the reader with a large amount of data of a more or less indefinite nature, a discussion of curly-top counts has been omitted from this report. Of the 12 tests reported, 5 showed damage by curly top to an intermediate extent, 2 showed very severe injury, and in the remaining 5 the plants were so slightly diseased as to be practically uninjured.

METHODS OF RECORDING DATA

As the most economical method of obtaining reliable results it was decided to limit the harvest records from the test fields chiefly to samples taken at random.[23] Each beet in the 20-beet samples was selected by counting a definite number, depending on the size of the field and the number of samples desired, and then taking the first normally competitive beet. The interval between beets chosen for a particular field was 25, 30, 50, or some other number that afforded a thorough sampling of the blocks. Normally competitive beets were selected in order to avoid beets that might have been favored by lack of competition. The normally competitive beet was only approximated, however, in some fields where there was not a good stand. If a consistent standard for competitive conditions had been maintained, many parts of some of the fields would have been skipped entirely. To avoid this difficulty, the standard held for competitive conditions came to depend entirely on the nature of the stand in each particular field.

As an example of the method of securing the harvest record, detailed data of the A. N. Wight planting, at Tremonton, Utah, are given in Table 13. Student's method (*10*) has been used in analyzing the results.

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[22] At the Frank Boyd farm, Fruita, Colo., where the first planting was lost from root rot, and at the Louis Spaulding farm, Hooper, Utah, where the first planting was blown out by a bad windstorm, second plantings were made at rather late dates.

[23] This method was recommended by A. W. Skuderna.

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TABLE 13.—*Comparison of the U. S. No. 1 variety with a commercial brand (Frederiksen), planted in 1931 on the Wight farm at Tremonton, Utah*

Weight of 20-beet samples (pounds)			Difference between sucrose percentage of U. S. No. 1 and commercial [1]
U. S. No. 1	Commercial	Difference [1]	
35.0	15.5	19.5	−0.9
31.0	18.0	13.0	−1.6
23.0	13.0	10.0	−1.2
31.0	17.5	13.5	− .7
35.5	19.0	16.5	−2.2
25.5	18.5	7.0	− .9
31.0	16.5	14.5	.1
26.0	27.0	−1.0	− .4
[2] 29.750	[2] 18.125	[2] 11.625±1.516	[2] .975±.169

[1] When the commercial exceeds U. S. No. 1 a minus sign is used.
[2] Average.

Only eight samples were taken from each strain, but the data obtained were so consistent as to make possible certain general conclusions. With one exception there was a consistent difference in the weight of the 20-beet samples in favor of the U. S. No. 1 variety, the average difference being 11.625 ± 1.516 pounds. According to the odds given in Student's tables (*2*), this difference might occur by chance alone once in 832 times. The average sucrose percentage was 19.10 for the commercial brand and 18.13 for the U. S. No. 1 variety, a difference of 0.97 ± 0.17 per cent. With only one exception the difference in sucrose percentage was consistently in favor of the commercial brand.

By taking into consideration the stand counts and assuming the weight per beet obtained from the 20-beet samples to be truly representative, a theoretical yield per acre may be readily calculated. On the Wight farm this gives 16.1 tons per acre for the U. S. No. 1 variety and 9.2 tons per acre for the commercial brand.[24] The values actually obtained from the record of the total weight of beets harvested were 16.4 tons per acre for the U. S. No. 1 variety and 8.6 tons per acre for the commercial brand.[25]

The closeness of agreement in yield estimates is very remarkable and helps to establish confidence in the method of estimating yields from the 20-beet samples. Eight was considered a very small number of samples from which to draw conclusions. If time had permitted, at least twice as many samples would have been taken. Although the 20-beet samples were intended to give only the approximate yield, yet their accuracy was such that there can be little doubt about the results on the Wight farm. The yield per acre was nearly doubled by the use of the resistant seed. Although the difference in sucrose percentage was nearly 1 per cent, in favor of the commercial brand, the sucrose percentage of the U. S. No. 1 variety (18.13) was acceptable.

[24] Actual stand as determined by counts in the blocks was used as a factor in arriving at these values.
[25] This record was taken by A. N. Wight with the cooperation of the Utah-Idaho Sugar Co. The figures were obtained through the courtesy of J. P. Holmgreen, field superintendent, Utah-Idaho Sugar Co., Garland, Utah. The total yield for the U. S. No. 1 variety was 34,323 pounds and for the commercial brand 18,112 pounds, and according to measurements taken by the writers 1.05 acres were devoted to each.

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COMPARATIVE DATA ON YIELDS

The final determinations of yields of beets and sugar are shown in Table 14. The actual data afford a measure of only the average weight per beet; but in order to compare the performance of the resistant variety and commercial brands, two columns of additional data have been calculated, namely, the yield in tons per acre and the yield of gross sugar in pounds per acre. As a basis for these calculations it seemed best to assume that a perfect stand (26,136 beets per acre) occurred in all cases. This basis is somewhat unfavorable to the resistant variety in most of the cases where curly top appreciably affected the yield, because the disease often reduces the stand and to a greater extent in the commercial brands than in the resistant variety. A striking example of this is shown in Table 12. A comparison of yields on the basis of actual stands is, however, apt to be confusing where differences in stands are due to factors other than the disease.

TABLE 14.—*Results from grower-test plantings of the U. S. No. 1 variety and commercial brands in Utah and Colorado in 1931*

[Data represent averages based upon 20-beet samples from replicated blocks of each variety]

(A) IRRIGATION WATER ADEQUATE; MEDIUM TO SEVERE CURLY TOP

Locality	Date of planting	Grower	Variety	Weight per beet [1]	Yield per acre [2]	Sucrose [3]	Gross sugar per acre [4]
				Pounds	*Tons*	*Per cent*	*Pounds*
Corinne, Utah	Apr. 2	A. M. Reeder	U. S. No. 1	1.89	24.7	17.5	8,644
			Dippe	1.41	18.4	18.3	6,744
			Difference	[5] .48	6.3	[5] −.8	1,900
		O. Christensen	U. S. No. 1	1.47	19.2	17.8	6,839
			Dippe	1.12	14.6	18.4	5,387
			Difference	[5] .35	4.6	[5] −.6	1,452
Tremonton, Utah	Apr. 7	A. N. Wight	U. S. No. 1	1.49	19.5	18.1	7,048
			Frederiksen	.91	11.9	19.1	4,543
			Difference	[5] .58	7.6	[5] −1.0	2,505
		C. W. Summers	U. S. No. 1	1.08	14.1	17.6	4,968
			Frederiksen	.45	5.9	17.8	2,093
			Difference	[5] .63	8.2	−.2	2,875
Lewiston, Utah	Apr. 25	D. Butters	U. S. No. 1	2.08	27.2	15.1	8,209
			R. & G. Pioneer	1.74	22.7	15.8	7,185
			Difference	[5] .34	4.5	[5] −.7	1,024

[1] Determined from 20-beet samples harvested as explained in the text.
[2] Calculated on the basis of a 100 per cent stand (26,136 beets per acre) by multiplying average weight per beet in pounds by 26,136 and reducing to tons.
[3] The writers are indebted to the Utah-Idaho Sugar Co. and to the Gunnison Sugar Co. for analyses made in connection with this work.
[4] Determined by multiplying yield per acre in pounds by average sucrose percentage, hence it may differ slightly from a weighted average.
[5] Shows statistical odds of 30 to 1 by Student's method of analysis (*1, 10*) that a difference as great as this was not due to chance alone.

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TABLE 14.—*Results from grower-test plantings of the U. S. No. 1 variety ana commercial brands in Utah and Colorado in 1931*—Continued

B) IRRIGATION WATER EXTREMELY INADEQUATE; VERY LITTLE CURLY TOP AT ASARCO FARM AND S. TAYLOR'S; SEVERE CURLY TOP AT N. P. ANDERSON'S AND L. SPAULDING'S

Locality	Date of planting	Grower	Variety	Weight per beet	Yield per acre	Sucrose	Gross sugar per acre
				Pounds	*Tons*	*Per cent*	*Pounds*
Magna, Utah	Mar. 24	Asarco farm	U. S. No. 1	1.36	17.8	15.2	5,403
			Elite Braune	1.33	17.4	17.4	6,048
			Difference	.03	0.4	[5]—2.2	—645
	Mar. 23	S. Taylor	U. S. No. 1	1.61	21.0	16.4	6,901
			Elite Braune	1.48	19.3	17.6	6,808
			Difference	.13	1.7	[5]—1.2	93
Elsinore, Utah	Apr. 15	N. P. Anderson	U. S. No. 1	.67	8.8	15.5	2,714
			Strube	.53	6.9	16.6	2,299
			Difference	[5].14	1.8	[5]—1.1	415
Hooper, Utah	Apr. 27	L. Spaulding	U. S. No. 1	.83	10.8	--------	--------
			R. & G. Old Type	.46	6.0	--------	--------
			Difference	[5].37	4.8	--------	--------

(C) IRRIGATION WATER ADEQUATE; VERY LITTLE CURLY TOP

Fruita, Colo	Apr. 14	J. H. Talbert	U. S. No. 1	1.89	24.7	17.6	8,694
			Elite Braune	1.93	25.2	17.6	8,878
			Difference	—.04	—.5	0	—184
	May 26	F. Boyd	U. S. No. 1	1.47	19.2	18.1	6,954
			Elite Braune	1.32	17.3	18.0	6,210
			Difference	.15	1.9	.1	744
Salt Lake City, Utah.	Apr. 14	M. Park	U. S. No. 1	1.44	18.8	17.5	6,586
			Elite Braune	1.42	18.6	17.8	6,606
			Difference	.02	.2	—.3	—20

[5] Shows statistical odds of 30 to 1 by Student's method of analysis (*1, 10*) that a difference as great as this was not due to chance alone.

Table 14, A, shows the results from 2 farms at Corinne, 2 at Tremonton, and 1 at Lewiston.[26] The districts at Corinne and Tremonton have come in recent years to have the reputation of being bad curly-top areas. Presumably the beet leaf hoppers reach these areas first in the course of the migration into the Bear River Valley. Lewiston, in Cache Valley, has not experienced heavy injury so often, but more or less damage has frequently been reported there. On all five farms the yield from the U. S. No. 1 variety was significantly greater than that from the commercial brands. Most of the yield comparisons are very clear cut. The 20-beet samples must have been very representative because of the remarkable uniformity.

Student's method (*10*) was used in analyzing the results. This was chiefly a matter of convenience, however, because the correlation between pairs was very small. The odds against the difference being

[26] The harvest at Butters' farm was completed by J. O. Culbertson, assistant agronomist, Division of Sugar Plant Investigations, and the analyses were made by the Amalgamated Sugar Co. The yield record secured on the Spaulding farm was likewise taken by J. O. Culbertson.

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due to chance were very great at Reeder's, Christensen's, and Summers' (over 2,000 to 1); at Wight's, 832 to 1; and at Butters', 103 to 1. In estimating the odds, the difference is referred to as either plus or minus. Probably the most striking field demonstration was on the Wight farm, where the actual yield was nearly doubled by the use of the resistant seed.

The percentage of sucrose for the beets from the farms listed in Table 14, A, except the Summers' farm, was significantly lower in the U. S. No. 1 variety than in the commercial brand. Larger beets, however, were used in the samples taken for analyses of the U. S. No. 1 variety. In each case the gross sugar per acre was very materially increased by the use of the resistant seed.

Table 14, B, shows three cases where the sucrose percentage of the U. S. No. 1 variety was very much lower than that of the commercial brand. At Asarco farm there was a difference of 2.2 per cent in

FIGURE 6.—Grower-test planting on the Anderson farm at Elsinore, Utah, showing the U. S. No. 1 variety at the right and a commercial brand (Strube) at the left. Planted April 15, 1931; photographed August 14, 1931

favor of the commercial brand. This exceptionally low sugar content may be partly explained by the nature of environmental conditions during the summer. At Asarco farm there was an excellent stand of beets in most of the field. Conditions were optimum for a thrifty growth until the middle of July, and only a very small percentage of beets showed symptoms of curly top. Very suddenly the water supply for irrigation was shut off completely. The field became drier and drier until the leaves wilted down almost completely every day. At this time, a fairly marked contrast was apparent between the U. S. No. 1 variety and the commercial brand. Especially in the driest portions of the field, the U. S. No. 1 variety seemed more resistant to the drought. It maintained a darker green color and in general a somewhat better appearance. This difference in reaction to an inadequate supply of moisture presumably accounts in some way for the marked difference in the sucrose percentage.

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The S. Taylor farm, at Magna, was within a short distance of Asarco farm and was affected by similar conditions as regards water. Here also the percentage of sucrose was exceptionally low in the U. S. No. 1 variety. At the N. P. Anderson farm, at Elsinore, the drought was very severe during most of the summer, but more especially during the first part of the growing season. Although the U. S. No. 1 variety was less injured by curly top than the commercial brand (Strube), as shown in the photograph taken August 14 (fig. 6), the yields obtained were so strongly influenced by the water shortage as to nullify largely the advantage arising from the resistance of the U. S. No. 1 variety. Table 14, B, shows very low yields at the Anderson farm, and again the sucrose percentage of the U. S. No. 1 variety was exceptionally low.

Through the courtesy of W. A. Shands, assistant entomologist, Bureau of Entomology, United States Department of Agriculture, at Grand Junction, Colo., two plantings were made possible in the Grand Valley of Colorado. Mr. Shands was well informed regarding invasions of the beet leaf hopper in the Grand Valley, and the plantings were located where considerable damage occurred in 1930. In 1931 migrations of leaf hoppers were known to have occurred, and the insects were observed in considerable numbers in both fields where the plantings were made. Nevertheless, the percentage of curly-top infection was light and seemed to be of a very mild type. At the end of the season, the observation of one of the writers (Owen) was that there was no appreciable damage from curly top in either the commercial brand or the U. S. No. 1 variety. Table 14, C, shows the results of both of the Colorado plantings. There was no significant difference in yield between the commercial brand and the U. S. No. 1 variety, and the percentage of sucrose was practically identical.

The grower-test plantings in Utah and Colorado have tended to confirm the results of the preliminary tests. Generally the sugar content was within close range of the commercial brands, but in three instances, because of severe drought, the difference in sucrose percentage was 1.1 to 2.2 per cent, in favor of the commercial brands used as checks. It is believed, however, that this condition was exceptional. Furthermore, it would be entirely impracticable to attempt to grow sugar beets without a better supply of moisture than was available in the three instances referred to.

COMPARATIVE DATA ON QUALITY

A question of vital interest to the manufacturers of beet sugar is the purity of the juice. An effort was made, therefore, to secure extensive data on the apparent-purity coefficients of the U. S. No. 1 beets in the various plantings. Table 15 shows that in some cases the apparent purity for the U. S. No. 1 variety is somewhat higher than that for the commercial brand and that in other cases it is slightly lower. As none of these differences is statistically significant, it seems safe to conclude that the apparent purity for the U. S. No. 1 variety is fully equal to that of the commercial brands used for comparison.

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TABLE 15.—*Apparent purity of the U. S. No. 1 variety compared with that of commercial brands*

Locality	Grower	Apparent purity			Number of comparisons between commercial and U. S. No. 1
		U. S. No. 1	Commercial	Difference [1]	
Corinne, Utah	A. M. Reeder	90.2	90.0	0.2	8
	O. Christensen	90.1	90.2	−.1	12
Tremonton, Utah	A. N. Wight	89.7	89.9	−.2	4
	C. W. Summers	89.7	89.0	.7	4
Magna, Utah	Asarco farm	87.3	86.1	1.2	3
	S. Taylor	88.7	87.6	1.1	7
Elsinore, Utah	N. P. Anderson	87.6	87.4	.2	20
Fruita, Colo	J. H. Talbert	90.4	91.2	−.8	12
	F. Boyd	88.7	88.6	.1	6
Salt Lake City, Utah	M. Park	89.2	88.5	.7	9
Weighted average		89.12	88.94	.176±.14	

[1] When the commercial exceeds U. S. No. 1 a minus sign is used.

SPECIAL DATA ON U. S. NO. 1

BOLTERS

Wherever the plantings were made early and cold weather occurred during germination, a few plants of the U. S. No. 1 variety were observed to form seed stalks. Occasionally a bolter was observed also in commercial brands, but not nearly so frequently.

On the station plot at Salt Lake City, Utah, the first plantings were made on March 23 and 24, 1931. This was a very early planting for this locality, and the weather became very cold during germination and early growth. The result was a fairly high percentage of bolters among strains that had a tendency in that direction. The bolters were undoubtedly in higher proportion here than in any of the grower-test plantings in Utah or Colorado. Out of 1,857 plants in the Salt Lake City plot, where conditions favoring bolting were most pronounced, 24, or 1.3 per cent, of the U. S. No. 1 variety produced seed stalks in this abnormal manner. Under the same conditions, among approximately the same number of plants, there were only two bolters in a commercial brand (Pioneer). In later plantings there was a very decided decrease in the percentage of bolters. Even special strains, selected for genetic investigations, that bolted over 50 per cent in the March 23 planting, did not bolt at all when planted May 19. In plots on the same field at Salt Lake City planted April 20 there was only 1 bolter among 646 plants of the U. S. No. 1 variety. In a planting made May 19 there was no bolting whatever. From this experience it would seem that the small amount of bolting which occurs in the U. S. No. 1 variety, while noticeable, is of almost negligible economic importance and is not likely, under Utah conditions, to be a factor in any but extremely early plantings.

VARIABILITY

As previously stated, the U. S. No. 1 variety was produced by combining various strains selected on the basis of curly-top resistance and commercial quality. Under conditions of severe curly-top infection, some plants of the U. S. No. 1 variety are rather susceptible; the

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majority, however, show a tolerance that is in decided contrast with that of commercial brands; and a few individuals seem to have a very high resistance.

The presence of these apparently extremely resistant individuals in the U. S. No. 1 variety was first observed in experimental plantings in 1930 near Castleford, Idaho.[27] Of these, the writers selected the most outstanding individuals, seed from which has now been produced and was subjected to critical tests during the summer of 1932.

Although the resistant plants selected at Castleford in 1930 appeared to be absolutely free from curly top while exposed to an extremely bad epidemic, yet soon after the roots were set out as mother beets the following spring severe cases of curly top developed. Some of these especially resistant individuals also showed conspicuous vascular discoloration in the root. It seems possible, therefore, that part of the apparent resistance may have been due to some environmental influence. A great many more selections were made in 1931, however, and the breeding work will soon indicate whether or not some of this apparently high resistance is truly heritable.

In these extremely resistant individuals there was a tendency for the root to be somewhat sprangled and for the crown to be large and of poor proportions. However, there were some very well-shaped roots among them, especially in the smaller individuals. Some individuals reached a large size, 8-pound to 10-pound beets being not at all uncommon.

The sugar content of these especially resistant large beets is also of considerable interest. Douglas Scalley, district manager of the Utah-Idaho Sugar Co., became interested in this point, and from the A. N. Wight farm at Tremonton, Utah, he secured three of the largest beets he could find. After removal of the crown, the average net weight per beet of these three beets was 4.5 pounds. The analyses as compared with analyses of 20-beet samples of the U. S. No. 1 variety and the commercial brand Frederiksen, made at the Garland factory, are shown in Table 16.[28]

During the harvest at the Wight farm, 30 of the especially resistant beets were taken by the writers for mother beets. The analyses of these beets in comparison with the agronomic samples are given in Table 17.[29]

TABLE 16.—*Comparison of three large, highly resistant sugar beets (U. S. No. 1 variety) with four random 20-beet samples of the U. S. No. 1 variety and a commercial brand (Frederiksen), taken from the Wight farm, Tremonton, Utah, in 1931*

[Analyses were made at the factory at Garland, Utah]

Data	Average weight per beet	Sucrose	Coefficient of apparent purity
	Pounds	*Per cent*	
Random 20-beet sample of commercial (Frederiksen)	1.01	18.6	89.8
Random 20-beet sample of U. S. No. 1	1.48	18.0	89.7
3 especially large beets of U. S. No. 1 [a]	4.50	16.5	88.5

[a] Selected by Douglas Scalley, district manager, Utah-Idaho Sugar Co.

[27] Experimental plantings made by C. E. Cormany.

[28] All figures were obtained through the courtesy of J. P. Holmgreen of the Utah-Idaho Sugar Co.

[29] These analyses were made at the Government laboratory at Salt Lake City. Comparisons can not be made directly with Table 14 because in that table analyses made by the Utah-Idaho Sugar Co. at Garland and those made at Salt Lake City are averaged together.

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TABLE 17.—*Comparison of 30 highly resistant sugar beets (U. S. No. 1) with four random 20-beet samples of the U. S. No. 1 variety and a commercial brand (Frederiksen), taken from the Wight farm, Tremonton, Utah, in 1931*

Data	Average weight per beet	Sucrose
	Pounds	*Per cent*
Random 20-beet sample of commercial (Frederiksen)	0.8	19.4
Random 20-beet sample of U. S. No. 1	1.5	18.3
30 especially resistant beets of U. S. No. 1	[1] 3.9	15.5

[1] The average weight per beet of the 30 especially resistant beets, including the crown, was 4.89 pounds. Assuming that 20 per cent of the beet would be topped off in commercial practice, the approximate average weight per beet, comparable to the other weights given, would be 3.9 pounds.

It will be noted that the results secured from the 30 especially large beets are not so favorable as those from the 3 taken by Scalley. The former averaged only 15.5 per cent sucrose, whereas the latter averaged 16.5 per cent. Nevertheless, when one considers the large size of some of these outstanding individuals (average weight, 3.9 pounds per beet) 15.5 per cent sucrose seems acceptable. Mention might also be made of the variability of the sucrose percentage among the 30 large beets. The individual having the lowest sucrose percentage weighed (with crown) 6.2 pounds and contained 11.4 per cent sucrose. The individual showing the highest sucrose percentage weighed 4.1 pounds (with crown) and contained 18.4 per cent sucrose. One exceptionally fine beet weighed 5.2 pounds (with crown) and had 17 per cent sucrose. The largest beet in the group weighed 9.3 pounds (with crown) and had 14.4 per cent sucrose.

By selecting the most resistant individuals and those having the best shape and sugar content, it is hoped to develop a much better strain of beets than the present U. S. No. 1 variety.

COMPARISON OF FIRST AND SECOND GENERATIONS

Of considerable importance is the performance to be expected from successive increases of the U. S. No. 1 variety reproduced without continued selection. In the present study the investigators have utilized the overwintering-in-the-field method of seed growing in which the seed is planted in September, the plants overwintered in the field, and the seed crop obtained in the early summer of the following year. This appears to be a practical method for growing seed in those portions of the United States where the winter conditions are mild (*11*), but it does not permit of any selection of mother beets.

All investigators who have experimented with the U. S. No. 1 variety recognize the desirability of further selection and breeding work with this and with other promising selections. Continued effort is being made by Government workers and sugar companies in this direction. Nevertheless, a very vital question must be decided in connection with the immediate utilization of the new variety. Only a few hundred pounds of the first increase of the original U. S. No. 1 seed are available. Will the succeeding generations maintain the standard sufficiently to make it worth while to reproduce second, third, and even fourth direct multiplications?

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From a theoretical standpoint, provided no unrecognized selections are taking place, it is difficult to see how a few generations of reproduction with full random mating could change the general constitution of the population of plants that make up a variety such as the U. S. No. 1. A careful observation of a field of sugar beets grown for seed, however, reveals the fact that full random mating may not be entirely possible. Even from transplanted mother beets there is a strong tendency for a certain percentage of the plants to flower earlier than the average and set seed in abundance; while other plants begin flowering later than the average, and many of these contribute very little or nothing to the following generation or "increase" of seed. With seed produced by overwintering plants in the field, this point is of particular interest because among closely spaced plants there is a very wide variation in time of flowering. What effect this uneven distribution in seed production has on the quality of the offspring can be determined only by experimental evidence. The greatest danger would appear to be in an increased percentage of plants that have a tendency to bolt, which is already an undesirable characteristic of the U. S. No. 1 variety. It is hoped, however, that undesirable tendencies will not be multiplied to an appreciable degree while the variety is being propagated to meet an emergency.

In 1931 an effort was made to secure preliminary data on the behavior of the first generation from the U. S. No. 1 seed as compared with a second generation (otherwise referred to in this paper as "first increase") reproduced at St. George, Utah, by the overwintering-in-the-field method. An effort was made to arrange plantings of the first and second generations of the U. S. No. 1 variety in such a way that a very critical comparison could be made. In order to have as many replications as possible, small plots were used. Each plot was made up of four rows 25 feet long and 20 inches apart. The plots were replicated up and down the field in a full random arrangement (*10*). A third strain, the commercial brand Pioneer, was used as a check. Only the two center rows were used for the harvest record. Ten replications were made at Salt Lake City, 10 at Granger, and 6 at Logan. At Granger a very severe epidemic of curly top was brought about by planting diseased mother beets in the vicinity of the experiment. At Salt Lake City curly top became severe during the latter part of the summer, but a very vigorous growth had already been made, so the disease did not have a marked effect upon the yield. The Logan planting was situated on the Greenville farm of the Utah Agricultural Experiment Station, where there was practically no damage from curly top. Table 18 gives a very brief summary of all the results.

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TABLE 18.—*Comparison of the first and second generations of the U. S. No. 1 variety with a commercial brand (Pioneer) in Utah in 1931*

[Results represent averages from the replicated plots]

Locality	Replications [1]	Yield per acre				Sucrose					
		U. S. No. 1		Commercial	Difference required for significance [2]	U. S. No. 1					Commercial
		First generation	Second generation			First generation	Second generation	Difference [3]	Variance of difference	Standard deviation of difference	
		Tons	*Tons*	*Tons*	*Tons*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Salt Lake City	10	25.5	25.1	19.6	3.4	13.31	13.92	−0.61±0.54	0.642	0.802	14.01
Logan	6	22.0	21.1	19.9	3.5	17.77	17.72	.05± .40	.353	.594	18.54
Granger	10	8.0	7.8	2.4	1.1	17.42	16.82	.60± .24	.124	.352	[4] 16.15
Weighted average	-------	-------	-------	-------	-------	-------	-------	− .13± .45	.436	-------	-------

[1] A sample of 20 normally competitive beets was taken from the 2 center rows of each plot for analysis, with the exception of the Granger plots, where 2 plots were required for a 20-beet sample of normally competitive beets.

[2] The odds necessary for significance are considered to be approximately 30 to 1. In estimating these odds, average standard deviations were calculated according to the method outlined by Student (*3*) and Student's tables published in Metron (*2*) were used in deriving the odds.

[3] The probable errors were derived by considering the results in pairs, i. e., the third variable (the commercial variety) was not considered in this comparison. By working out an average variance including the third strain a slightly smaller probable error was secured for the Salt Lake City plot (0.423 instead of 0.540).

[4] Approximation derived from the sucrose in the juice. The commercial beets (Pioneer) on the Granger plot were too small to rasp and run with the cold-water-digestion method. For the other sucrose determinations the Sachs-Le Docte cold-water-digestion method was used.

Table 18 shows that the acre yields of the first and second generations of the U. S. No. 1 variety were almost identical. With the exception of the Logan results, there was, however, a very decided increase over the commercial brand Pioneer. At Salt Lake City the difference in sucrose percentage was 0.61,[30] in favor of the second generation; at Granger the difference was 0.60, in favor of the first generation. At Logan the sucrose percentages for the two different generations were practically equal.

No differences in bolting tendency were ascertained. In the entire test there were 8 bolters in the first generation of U. S. No. 1 variety, 7 bolters in the second generation, and 1 bolter in the commercial brand.

It is perhaps unfortunate that a still more extensive experiment was not carried out, but from the results available the second generation of the U. S. No. 1 variety does not appear to be significantly different from the first generation.

More experimental evidence is highly desirable, especially from the third, fourth, and fifth generations of this seed, reproduced in the same manner as the second generation, that is, by overwintering the plants in the field and without any selection. This method, moreover,

[30] On the plots at Salt Lake City a great deal of difficulty was experienced in securing irrigation water during the summer, as the supply of water was always exhausted before it reached the end of the rows. This irregular irrigation seemed to affect the percentage of sucrose even more than the yield. The sucrose percentages for the Salt Lake City plots were so extremely variable that the difference between the two generations of the U. S. No. 1 variety (0.61±0.54) was less than twice its probable error and was wholly insignificant. The difference in sucrose percentage at Granger (0.60±0.24), however, indicated much less variability.

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if the results proved satisfactory, would be especially suitable to American conditions.

At various times the sugar-beet companies in this country have grown their own seed from commercial brands imported from Europe. Frequently these increases have been made without any effort at selection. Generally good results have been reported, but it is unfortunate that more experimental evidence is not available to show whether the seed of the second generation was genetically inferior or superior to the parental material.

Dean A. Pack became interested in this problem, and initiated two experiments. In 1929 commercial Braune seed was secured, and a random sample was taken for increasing at St. George, Utah, by planting in September and harvesting the next spring. The progenies from the St. George increase were compared with the parental seed on the experimental plots of the Gunnison Sugar Co. in 1930. Stands were not sufficiently comparable to enable one to judge yielding ability, but eight 5-beet samples from each failed to reveal any significant difference in percentage of sucrose. A sample from a lot of Pioneer was grown in a similar manner at St. George in 1930. This seed was compared with the parental Pioneer in 1931. The plan of the experiment was very similar to that described for the two generations of the U. S. No. 1 variety. There were 10 replications at Salt Lake City, 10 at Granger, and 6 at Logan. There were no significant differences in yield. At Salt Lake City there was a difference of 0.66 ± 0.20 in sucrose percentage, in favor of the original German seed, but a high probable error is associated with the difference for reasons given in footnote 30, page 38. At Logan there was a difference of 0.25 in sucrose percentage in favor of the parental seed. At Granger the two generations tested exactly the same in sucrose percentage.

The results of these tests indicate that, contrary to common belief, the second generation of sugar-beet seed from commercial brands does not immediately show great deterioration in the quality of the sugar beets produced. This conclusion seems justified also by the genetic considerations involved.

TESTS IN CALIFORNIA [31]

Agronomic-evaluation studies on the curly-top-resistant variety U. S. No. 1 have been conducted in California for two years. In 1930, the trial plantings were located at Shafter and Bakersfield, an area where the beet leaf hopper breeds abundantly and where any plantings of beets are almost invariably subject to heavy infestation. Beet culture was started a number of years ago on a large scale in this portion of the San Joaquin Valley, but after the disastrous outbreak of 1919 was abandoned.

The tests conducted in 1931 were on a more extensive scale. In conference with A. W. Skuderna, it was decided to distribute the agronomic tests and the grower-test plantings in such a manner that the U. S. No. 1 variety might be studied when exposed to different

[31] Contributed by Charles Price and Eubanks Carsner. The experimental work at Bakersfield, Buttonwillow, Chino, Dos Palos, Firebaugh, Oxnard, and Shafter was conducted by Price. The grower-test plantings in the central California area were handled by Carsner. Acknowledgment is due Glenn E. Gillespie, scientific aide, for assistance in the work conducted by Price.

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degrees of curly top and when not exposed to the disease. The localities chosen and the curly-top hazard to be expected in each were as follows:

Oxnard.—In this locality losses from curly top are usually so slight as to be negligible.

Chino.—The curly-top disease in this area is more severe than at Oxnard; the most severe outbreaks have caused serious losses. The crop damage ordinarily caused by the disease may be classed as slight to moderate.

Shafter, Buttonwillow, Bakersfield, Firebaugh, and Dos Palos.—These places in the San Joaquin Valley were selected because of their location within the breeding area of the beet leaf hopper. Sugar-beet growing had been carried on from time to time, and factories had been established in the southern portion of the San Joaquin Valley. These had been abandoned for a number of causes, among which the curly-top disease was undoubtedly of major importance, and it was commonly conceded that sugar-beet growing in the entire southern area of the valley was extremely hazardous.

Manteca.—This district, at the northern end of the San Joaquin Valley, is practically on the edge of a vast leaf-hopper breeding area and has regularly suffered heavy losses from curly top.

Union Island, McDonald Island, and Clarksburg.—These districts are in the same general area. Clarksburg is in the lower Sacramento Valley; Union Island and McDonald Island are in the delta of the San Joaquin and Sacramento Rivers. These areas regularly experience some curly-top damage, and sometimes the damage is very great.

King City.—This area, in the southern Salinas Valley, has suffered severely and rather regularly for many years.

The tests undertaken have been of two sorts: (1) Intensive agronomic tests in which close evaluation was attempted by means of small plots frequently replicated, and (2) test plantings, usually in cooperation with a local grower, in which direct comparison of the U. S. No. 1 variety with a commercial brand was obtained by planting a series of alternating strips of the two sorts under consideration in fairly large field plantings. In two of these tests, several planting dates were used in order to provide various conditions of exposure.

INTENSIVE AGRONOMIC TESTS

TESTS AT SHAFTER

The tests at Shafter were conducted from February 6, 1930, to July 9, 1931, on land secured from the United States Cotton Field Station. In the first test the seed, which was planted Feburary 6, 1930, was of the following types: Seed of the U. S. No. 1 variety produced from the mother beets selected in 1929 at Twin Falls, Idaho, (p. 9); seed of a commercial brand (Old Type); and seed of another strain. Since only the comparison of the U. S. No. 1 variety with the commercial brand is of interest in this investigation, the data given herein refer only to these two lots.

In the 1930 test each plot consisted of four rows 60 feet long and 24 inches apart. The plots were arranged in four randomized blocks, thus furnishing four replications of the three seed lots. A stand of approximately 100 per cent was obtained in this planting. The yields were determined by weighing all the beets in a plot. Sucrose percentage and coefficient of apparent purity were determined on five 10-beet samples of normally competitive beets (p. 12) taken from the center two rows of each plot. The results as given are averages of the individual determinations. (Table 19, A.)

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TABLE 19.—*Comparison of the U. S. No. 1 variety with a commercial brand (Old Type) at Shafter, Calif., in 1930 and 1931*

[Data represent averages from replicated plots each consisting of 4 rows 160 feet long and 24 inches apart]

Year and variety	Plots	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
					Gross	Indicated available
	Number	*Tons*	*Per cent*		*Pounds*	*Pounds*
(A) 1930:						
U. S. No. 1	4	23.073	16.77	86.25	7,739	6,675
Commercial (Old Type)	4	20.568	16.60	85.82	6,828	5,860
Difference	--------	2.505	.17	.43	911	815
(B) 1931:						
U. S. No. 1	15	7.398	15.20	80.6	2,249	1,813
Commercial (Old Type)	5	4.029	14.50	80.8	1,168	944
Difference	--------	3.369	.70	−.2	1,081	869

The yields obtained were high, doubtless because of the comparatively mild curly top of the 1930 growing season. On April 2, 3 per cent of the U. S. No. 1 variety and 27 per cent of the commercial brand showed mild curly top. On June 7, 5 per cent of the U. S. No. 1 variety and 40 per cent of the commercial brand showed mild curly top. It was noted at the close of the season that the U. S. No. 1 variety remained green, whereas the commercial brand was beginning to turn yellow.

The average yield of the U. S. No. 1 variety was greater than the yield of the commercial brand, the difference being 2.505 tons per acre. Because of the range of values obtained in the individual plots, it is doubtful whether this difference is significant. The sucrose percentages and the apparent-purity coefficients were not significantly different. The greater sugar-per-acre yield for the U. S. No. 1 variety was due to the higher tonnage for that variety.

In the test at Shafter in 1931, five seed lots were used, each of which was replicated five times. The plots were arranged in a Latin square. The planting was made from February 3 to 6.

The five seed lots consisted of the three increases of the original seed stock of the U. S. No. 1 variety, a commercial brand of seed (Old Type), and seed of another strain.

A heavy influx of beet leaf hoppers occurred just after thinning when the beets were in the 8-leaf stage. On April 4, counts of leaf hoppers showed about one leaf hopper per plant. At this time no disease was evident in any of the plots. Later examinations showed the following average percentages of infected plants: For the U. S. No. 1 variety, 1, 34, and 95 per cent; and for the commercial brand, 13, 88, and 100 per cent, on April 17, May 3, and June 8, respectively. After June 8 the curly-top percentages remained fairly constant. At this time distinct yellowing was shown by the commercial brand, in contrast to the green color of the U. S. No. 1 variety.

Unfortunately, the garden nematode was generally present throughout these plots and greatly affected the yields obtained. At the time of harvest an attempt was made to secure comparable samples for determining yield and sucrose percentages from the normally

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competitive beets showing the least nematode injury in the various plots.

No significant differences were found among the three seed lots of the U. S. No. 1 variety produced in Utah, California, and New Mexico, respectively.[32] The data given represent averages of the 15 plots of the U. S. No. 1 variety as compared with the average of the commercial brand used as a check. (Table 19, B.)

Conclusions from this test are presented tentatively because of the nematode complication, which prevented accurate evaluation of the extent of curly-top injury. Assuming a fairly uniform effect of the nematodes, as seems justified from the field observations, and taking into consideration the attempt made to choose the plants least affected, the yields may be considered fairly indicative of the performance of the U. S. No. 1 variety as compared with that of the commercial brand. The yield of the resistant variety was significantly greater than the yield of the commercial brand. Only the three plots highest in yield of the commercial brand equaled or exceeded the plot lowest in yield of the U. S. No. 1 variety. The average sucrose percentages showed a difference of 0.7, in favor of the U. S. No. 1 variety, a difference found not to be significant. Similarly, the coefficients of apparent purity were practically equal. The yield of sugar per acre, in which weight, sucrose percentage, and the coefficient of apparent purity enter as factors, was almost twice as great for the U. S. No. 1 variety as for the commercial brand.

TESTS AT BAKERSFIELD

In order to compare the performance of the U. S. No. 1 variety with that of a commercial brand, plantings were made in 1930 and 1931 near Bakersfield, Calif.

The 1930 tests were made with seed from the original selection of the resistant variety. The commercial brand used as a check was Old Type. Because of the limited amount of land available, only one plot was planted to each variety. Each of these two adjacent plots consisted of eight rows 160 feet long and 24 inches apart. The experiment was conducted under optimum conditions of soil, moisture, and fertility. Because of the early date of planting (January 6) the plants did not suffer maximum damage from curly top. On June 4, when the plants were 5 months old, 27 per cent of the commercial brand and 5 per cent of the U. S. No. 1 variety showed curly top. The type of curly top was considered mild. The yield data were obtained by harvesting the entire plot. Determinations of sugar percentage and of coefficient of apparent purity were made on five 10-beet samples of normally competitive beets.

The results of this test are given in Table 20. It will be noted that under the conditions of this experiment the commercial brand exceeded the U. S. No. 1 variety by 1.9 tons per acre in yield and by 0.8 in sucrose percentage. The small number of plots did not permit determination of significance in this experiment.

[32] These data were computed by the analysis-of-variance method but are not reported in detail on account of the nematode complication.

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TABLE 20.—*Comparison of the U. S. No. 1 variety with a commercial brand (Old Type), planted in January, 1930, at Bakersfield, Calif.*

[Data obtained from one plot for each variety, consisting of eight rows 160 feet long and 24 inches apart]

Variety	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
				Gross	Indicated available
	Tons	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1	18.88	16.1	83.6	6,079	5,082
Commercial (Old Type)	20.80	16.9	83.5	7,030	5,870
Difference	−1.92	−.8	.1	−951	−788

The 1931 tests at Bakersfield were made with the first Beaumont multiplication of the original seed of the resistant variety. The same general planting arrangement was followed as in 1930, except that beets were planted on three dates (January 6, February 10, and March 3), two plots being put out for each type under test. Beet leaf hoppers were noticed on the plants as early as April 7. The first disease counts were made on April 17. The detailed readings of curly-top incidence in these plots are shown in Table 21. The January plantings showed very little curly top throughout the season in comparison with the later plantings. The February plantings were more severely diseased than the January plantings but did not show at the close of the season so high a percentage of curly top as the March plantings. In the March plantings the commercial brand used as a check was very severely affected, the disease incidence reaching 100 per cent on June 8. In the U. S. No. 1 variety 92 per cent curly top was found at the time of this count.

TABLE 21.—*Percentage of plants showing curly top in the U. S. No. 1 variety and in a commercial brand (Old Type), at Bakersfield, Calif., in 1931*

[Data represent averages from two plots, each consisting of eight rows 160 feet long and 24 inches apart]

Variety	Date of planting	Percentage of plants showing curly top on—		
		Apr. 17	May 3	June 3–8
U. S. No. 1 [1]	Jan. 6	1	----------	4
Commercial (Old Type)	do	6	----------	18
U. S. No. 1 [1]	Feb. 10	5	----------	8
Commercial (Old Type)	do	15	----------	30
U. S. No. 1 [1]	Mar. 3	8	8	[2] 29
Commercial (Old Type)	do	25	30	[2] 100

[1] First Beaumont multiplication of original seed.
[2] These counts were made June 8, 1931.

The yield data were based on normally competitive beets from the center four rows of each plot. The yields per acre were computed on the basis of a 100 per cent stand. Determinations of sucrose percentage and coefficient of apparent purity were made from three 20-beet samples from each plot.

Table 22 shows that the U. S. No. 1 variety outyielded the commercial brand, especially in the plantings of February 10 and March 3, where curly top was an important factor. In the March planting the commercial brand yielded only 3.92 tons per acre, a yield far below the cost of production, whereas the U. S. No. 1 variety yielded

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11.87 tons per acre. In sucrose percentage and coefficient of apparent purity, the U. S. No. 1 variety, contrary to expectation, exceeded the commercial brand in the February and March plantings. These results seem to indicate that under the conditions of the test the resistant types did not definitely tend to be lower than the commercial brand in sucrose percentage or apparent purity. In yield of sugar per acre, the U. S. No. 1 variety exceeded the commercial brand, especially in the February and March plantings. In indicated-available sugar, the U. S. No. 1 variety greatly exceeded the commercial brand, except in the January planting.

TABLE 22.—*Comparison of the U. S. No. 1 variety with a commercial brand at Bakersfield, Calif., in 1931*

[Data represent averages from two plots, each consisting of eight rows 160 feet long and 24 inches apart]

Variety	Date of planting	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [1]	
					Gross	Indicated available
		Tons	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1	Jan. 6	27.87	13.4	71.83	7,471	5,366
Commercial (Old Type)	do	26.89	13.7	78.52	7,370	5,787
Difference		.98	−.3	−6.69	101	−421
U. S. No. 1	Feb. 10	24.61	15.20	76.30	7,481	5,708
Commercial (Old Type)	do	15.02	14.15	70.89	4,250	3,013
Difference		9.59	1.05	5.41	3,231	2,695
U. S. No. 1	Mar. 3	11.87	14.0	71.53	3,323	2,377
Commercial (Old Type)	do	3.92	13.3	69.92	1,042	729
Difference		7.95	.7	1.61	2,281	1,648

[1] Obtained by averaging computed sugar yields for the individual plots; hence differing slightly from the product of the means given in this table.

Because of the limited number of plots, it was not possible to estimate statistically the significance of the differences found in this test. It is very clear, however, that where curly top entered as an important factor the trend was strongly in favor of the U. S. No. 1 variety. As curly-top exposure in this experiment was much more severe than is usually encountered by early-planted beets in California, the performance of the U. S. No. 1 variety is noteworthy.

TESTS AT BUTTONWILLOW

Agronomic tests of the U. S. No. 1 variety in comparison with a commercial brand (Old Type) were carried out at Buttonwillow in 1931.

Seed was planted on January 13 and February 12. For the January planting the seed of the U. S. No. 1 variety consisted of three increases of the original seed stock produced at Las Cruces, N. Mex.; St. George, Utah; and Beaumont, Calif., respectively. In the test, these separate increases of the U. S. No. 1 variety were treated as individual varieties and data obtained from each. The plots, each consisting of 8 rows 174 feet long and 20 inches apart, were planted in 5 replications systematically arranged. Each replication consisted of a block of four plots planted to the three U. S. No. 1 increases and to the commercial brand, respectively.

A heavy infestation of beet leaf hoppers, which occurred early in April, resulted in very little injury to the January plants, because

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of the preference of the leaf hoppers for the younger plants (February planting) and owing also to the large size of the January plants at the time of exposure and to the mild type of the disease. At harvest time (August 7) there was a definite color contrast between the resistant variety and the commercial brand, the latter being the yellower.

The results of the test are given in Table 23. The three increases of the U. S. No. 1 variety show no significant differences in average weight of individual beets, sucrose percentage, or coefficient of apparent purity. As compared with the commercial brand used as a check, two of the U. S. No. 1 lots were significantly [33] better in weight, and one was on the border line of being significantly better. No significant differences in sucrose percentage between the U. S. No. 1 lots and the commercial brand (Old Type) were found, one exceeding the commercial brand slightly, and two being slightly below it. The commercial brand had the higher coefficient of apparent purity, but the difference in only one case approached significance. It may be concluded that in weight of beets the trend is strongly in favor of the resistant U. S. No. 1 variety and that there are no positive indications of significant differences in quality.

TABLE 23.—*Comparison of three increases of the U. S. No. 1 variety with a commercial brand (Old Type), planted January 13, 1931, at Buttonwillow, Calif.*

[Data represent averages from five plots, each consisting of eight rows 174 feet long and 20 inches apart]

Variety	Weight of individual beets	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [1]	
					Gross	Indicated available
U. S. No. 1 increase:	*Pounds*	*Tons*	*Per cent*		*Pounds*	*Pounds*
(A) Beaumont, Calif.	1.852±0.058	24.202±0.758	14.88±0.23	78.12±0.57	7,186±196	5,606±121
(B) St. George, Utah	1.690± .066	22.111± .862	15.22± .28	75.85±1.13	6,736±316	5,134±304
(C) Las Cruces, N. Mex.	1.574± .076	20.569± .993	14.74± .23	78.27±1.02	6,054±277	4,716±167
(D) Commercial (Old Type)	1.394± .015	18.217± .196	15.10± .33	81.00±1.36	5,497±208	4,440±154
Difference:						
A−D	[2] .458	[2] 5.985	−.22	−2.88	[2] 1,689	[2] 1,166
B−D	[2] .296	[2] 3.894	.12	−5.15	[2] 1,239	694
C−D	.180	2.352	−.36	−2.73	557	276

[1] Obtained by averaging individual plot values; hence it differs slightly from product of means given in this table.
[2] Significant.

On February 12, plots of each of the U. S. No. 1 seed increases were planted alternately with check plots of the commercial brand (Old Type). Each plot consisted of eight rows 174 feet long and 20 inches apart.

The harvest record was obtained by determining the net weight of all beets produced in one plot of each increase of the resistant variety and in two plots of the commercial brand. This procedure was necessary in order not to interfere with the harvesting operations of the cooperator. In view of the fact, however, that there was no significant difference among the three increases of the U. S. No. 1 variety, the three plots of the resistant variety harvested may be

[33] The probable error was computed by Bessel's formula:

$$\text{P. E.}=0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}.$$

If the difference between two means was three times its probable error, it was regarded as significant.

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considered as replications. Yield per acre was computed from the actual plot yield. The determinations of sucrose percentage and coefficient of apparent purity were based on three 20-beet samples. The results are given in Table 24.

TABLE 24.—*Comparison of three increases of the U. S. No. 1 variety with a commercial brand (Old Type), planted February 12, 1931, at Buttonwillow, Calif.*

Variety	Plots	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
					Gross	Indicated available
	Number	*Tons*	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1 increase from—						
Beaumont, Calif.	1	25.262	15.4	78.12	7,781	6,079
St. George, Utah	1	21.426	15.8	75.85	6,771	5,136
Las Cruces, N. Mex.	1	17.272	15.8	77.59	5,458	4,235
Average	1	21.320	15.7	77.19	6,670	5,150
Commercial (Old Type)	2	13.026	15.5	80.99	4,038	3,270
Difference	------	8.294	.2	−3.80	2,632	1,880

Curly top injured this planting considerably, especially the commercial brand. An invasion of beet leaf hoppers occurred early in April; on April 7 it was estimated that the population was about one insect per plant. There was marked color contrast between the resistant variety and the commercial brand as early as April 20; the commercial plants at that time were beginning to show a yellow color. On May 3, 17 per cent of the commercial brand and 2 per cent of the U. S. No. 1 variety were diseased with curly top. The disease increased sharply, and on June 8 both the commercial brand and the U. S. No. 1 variety showed 100 per cent curly top.

The yields of the resistant variety in the January tests were very closely duplicated in the February planting. The yield of the commercial brand in the latter planting was, however, sharply depressed because of the more severe curly-top involvement. The quality of the sugar beets was practically the same. The average sucrose percentage of the U. S. No. 1 variety slightly exceeded that of the commercial brand, and the difference between the coefficients of apparent purity was slightly in favor of the commercial brand. The computed values for sugar per acre, both gross and indicated available, show the marked differences between the resistant and nonresistant sugar beets under curly-top conditions.

TESTS AT OXNARD AND CHINO

In an intensive agronomic test at Oxnard in 1931 comparison was made of the results from the three increases of U. S. No. 1 seed, a commercial brand of seed, and another strain.

The plots in this experiment were arranged in a Latin square. Each plot consisted of four rows 73 feet long and 20 inches apart. The planting was made on April 8, 1931.

The yield data were obtained from normally competitive beets. Yield per acre was computed on the basis of a 100 per cent stand. Sucrose percentage and apparent purity were determined on three 20-beet samples of normally competitive beets from each plot. The results given in Table 25 were computed from the data by Fisher's analysis-of-variance method (*9*). The significance of the differences found has also been determined for certain data.

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TABLE 25.—*Comparison of three U. S. No. 1 increases with a commercial brand (Old Type) at Oxnard and Chino, Calif., in 1931*

Variety	Oxnard test [1]					Chino test [2]					Average of Oxnard and Chino test				
	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [3]		Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [3]		Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [3]	
				Gross	Indicated available				Gross	Indicated available				Gross	Indicated available
U. S. No. 1 increase from—	*Tons*	*Per cent*		*Pounds*	*Pounds*	*Tons*	*Per cent*		*Pounds*	*Pounds*	*Tons*	*Per cent*		*Pounds*	*Pounds*
Las Cruces, N. Mex	26.502	13.48	83.48	7,135	5,954	24.568	14.08	86.30	6,894	5,944	25.535	13.78	84.89	7,014	5,949
Beaumont, Calif	28.854	13.02	82.49	7,485	6,173	24.672	14.48	87.00	7,145	6,208	26.763	13.75	84.74	7,315	6,190
St. George, Utah	26.842	12.84	80.26	6,874	5,509	25.875	14.38	85.72	7,420	6,360	26.358	13.61	82.99	7,147	5,934
Average	27.399	13.11	82.08	7,164	5,878	25.038	14.31	86.34	7,153	6,171	26.219	13.71	84.21	7,159	6,024
Commercial (Old Type)	26.633	12.61	78.16	6,717	5,253	25.169	13.34	85.72	6,667	5,704	25.901	12.97	81.94	6,692	5,478
Difference	.766	.50	3.92	447	625	—.131	.97	.62	486	467	.318	.74	2.27	467	546
z [4]	.1889	.4057	.4260	.2925	.5508	.0409	.3994	--------	.6190	.6129	--------	--------	--------	--------	--------
Standard error	--------	--------	--------	--------	--------	--------	--------	--------	559	522	--------	--------	--------	--------	--------
Standard error of mean	--------	--------	--------	--------	--------	--------	--------	--------	250	234	--------	--------	--------	--------	161
Standard error of difference	--------	--------	--------	--------	--------	--------	--------	--------	354	330	--------	--------	--------	--------	228
Difference required for significance	--------	--------	--------	--------	--------	--------	--------	--------	708	661	--------	--------	--------	--------	456

[1] Data represent averages from 5 plots, each consisting of 4 rows 73 feet long and 20 inches apart, planted Apr. 8.
[2] Data represent averages from 5 plots, each consisting of 4 rows 65 feet long and 20 inches apart, planted Mar. 10.
[3] Obtained by averaging individual plot values; hence it differs slightly from products obtained from the means given in this table.
[4] z=one-half the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z=0.5907; 1 per cent point=0.8443.

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Curly top did not enter as a factor into the Oxnard tests, being present in less than 1 per cent of the plants. The plots were severely injured by a general attack of the leaf-spot disease, and to this the low sucrose percentage obtained throughout the test can safely be assigned.

The arrangement of the plots and the statistical analysis employed have permitted the determination of the standard error of the experiment. This analysis reveals no significant differences among the varieties under these conditions, where curly top was not a factor. In sucrose percentage and in coefficient of apparent purity the data tend to corroborate the results reported from other California localities.

An intensive agronomic test, duplicating the Oxnard test, was conducted at Chino in 1931, planting being made on March 10. In this test comparisons were made of the three increases (made at Beaumont, Calif.; St. George, Utah; and Las Cruces, N. Mex.) of the original U. S. No. 1 seed with one another and with a commercial brand (Old Type) commonly used in this area. The plots, each of which consisted of four rows 65 feet long and 20 inches apart, were arranged in a Latin square.

Curly top was but a slight factor in the experiment. At harvest time the percentage of disease was small, and all cases were of the mild type. There was considerable injury from the leaf-spot disease, but this damage is represented by a reduction in sucrose percentage rather than by a reduction in weight.

Data from the plots were obtained from the center two rows, and only normally competitive beets were taken. Acre yields were computed on the basis of a 100 per cent stand. The determinations of sucrose percentage and coefficient of apparent purity were obtained from three 20-beet samples of normally competitive beets from each plot. Results are given as averages of individual readings.

From the data of the individual plots it has been possible (by Fisher's analysis-of-variance method) to determine the significance of the differences.

In agreement with the results of the test at Oxnard, the test at Chino demonstrated no significant differences in yield per acre, sucrose percentage, or coefficient of apparent purity. The values for sugar per acre, both gross and indicated available, show a certain degree of significance, corresponding to odds of approximately 20 to 1 that the differences obtained were not due to chance. This degree of significance indicates that a fair degree of reliance may be placed on the test and suggests a cumulative effect of the factors previously listed as not significantly different. In this test one of the U. S. No. 1 increases was significantly better than the commercial brand in sugar per acre, but the two other increases were not shown by the test to be better than the commercial brand. Under the conditions at Chino, however, where curly top was not a factor, it could not be shown that the commercial brand had an advantage over the U. S. No. 1 variety in any attribute measured, and it is fairly reasonable to assume a slight superiority of the U. S. No. 1 variety.

The differences among the three increases of the U. S. No. 1 variety were not significant in any attribute measured.

Since the Oxnard and Chino tests so nearly duplicate each other, it is possible to use the two experiments as the basis for an estimate

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of the behavior of the U. S. No. 1 variety as compared with that of the commercial brand. (Table 25.) It seems fair to take the average of the three increases of the U. S. No. 1 variety for this comparison, attributing to each mean the standard deviation of the mean found for the experiment.

The standard error of the mean for the two tests was calculated from $\frac{1}{2}\sqrt{V \text{ Chino} + V \text{ Oxnard}}$, which equals 161 pounds. Multiplying by $\sqrt{2}$, 228 was obtained as the standard error of the difference between the mean yields at the two places. The difference in indicated-available sugar, 546, is therefore significantly in favor of the U. S. No. 1 variety, the odds being approximately 72 to 1 that the difference between the U. S. No. 1 variety and the commercial brand would again be in favor of the U. S. No. 1 variety if the two kinds were grown again under similar conditions.

In these experiments the curly-top injury was negligible. It is noteworthy that the U. S. No. 1 variety was apparently the equal of the commercial brand of sugar beets in all important attributes, and that in every case it exceeded the commercial brand in sucrose percentage and in coefficient of apparent purity, though not by significant amounts.

GROWER-TEST PLANTINGS

PLANTING AT FIREBAUGH

A grower-test planting was made at Firebaugh, January 15, 1931, to compare the U. S. No. 1 variety of sugar beets with a commercial brand (Old Type). The seed of the U. S. No. 1 variety used was the first multiplication of the original selection and had been increased at Beaumont, Calif., in 1930. Plots consisting of 12 rows 171 feet long and 20 inches apart were used. Two plots were planted with each type of seed, resistant and nonresistant (commercial). The soil contained a large amount of organic matter and required irrigation only four times during the growing season. The beets in all the plots made a luxuriant top growth. A heavy infestation of the plants by the beet leaf hopper occurred early in April, but because of the comparatively mild type of disease that developed and also because of the size of the plants when first exposed, the injury was not very great. At the time of harvest (July 27) there was a marked contrast in color between the resistant variety and the commercial brand. The commercial-brand plots showed strikingly more yellow color. On June 8, 39 per cent of the U. S. No. 1 variety and 91 per cent of the commercial brand showed curly top. All the normally competitive beets in the four center rows of each plot were taken for the weight determinations. For determinations of sucrose percentage and coefficient of apparent purity, three 20-beet samples were taken from the normally competitive beets of the four center rows of each plot.

The results of this experiment are given in Table 26. The yield from the U. S. No. 1 variety exceeded that from the commercial brand by 5.4 tons per acre. No marked difference in sucrose percentage or in coefficient of apparent purity was found. The indicated-available sugar of the U. S. No. 1 variety exceeded that of the commercial brand by 1,440 pounds per acre. Although this experiment did not permit the determination of the statistical significance of these figures, the results seem to indicate a strong trend in favor of the U. S. No. 1 variety.

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TABLE 26.—*Comparison of the U. S. No. 1 variety with a commercial brand (Old Type), planted January 15, 1931, at Firebaugh, Calif.*

[Data represent averages from 2 plots, each consisting of 12 rows 171 feet long and 20 inches apart]

Variety	Percentage of plants showing curly top [1]	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
					Gross	Indicated available
		Tons	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1	5	20.255	17.75	81.06	7,191	5,829
Commercial (Old Type)	27	14.831	17.77	83.26	5,271	4,389
Difference		5.424	−.02	−2.20	1,920	1,440

[1] Based on counts made May 3, 1931.

PLANTING AT DOS PALOS

A grower-test planting was made at Dos Palos, on January 15, 1931. Because of unfavorable soil conditions and difficulties in regard to supervision resulting in poor cultural care, no attempt was made to secure yield records. Certain observations made during the course of the season are, nevertheless, of interest. The exact date of the principal influx of beet leaf hoppers is not known, but the plots were found to be heavily infested on May 4. On June 9, it was possible to distinguish the resistant from the check plots (Old Type) but the differences in color and size were not pronounced. On that date 85 per cent of the Old Type plants and 42 per cent of the U. S. No. 1 plants were diseased. The type of disease was very mild in the resistant plots. On July 4, both the resistant variety and the commercial brand showed 100 per cent curly top. There was then a very definite color contrast, the Old Type plots being much more yellow than the U. S. No. 1 plots.

PLANTINGS IN CENTRAL SUGAR-BEET AREA [34]

Additional grower-test plantings were made in the following localities: One near Clarksburg, in the southern end of the Sacramento Valley; 1 on McDonald Island and 1 on Union Island, in the peat-land delta of the San Joaquin and Sacramento Rivers; 1 near Manteca, at the northern end of the San Joaquin Valley; and 1 near King City, in the southern part of the Salinas Valley.[35] In previous seasons sugar beets in the King City and Manteca areas had been regularly affected more or less severely by curly top. Clarksburg, McDonald Island, and Union Island, while regularly suffering some damage, had in general been less severely exposed.

Because of circumstances beyond the control of the investigators, the only data obtained from the Clarksburg planting were those on the comparative rate of development of infection in the resistant variety and the commercial brand. For the same reason, records secured at King City were likewise inadequate. When examined shortly before harvest in midseason, the plots in both localities showed striking differences in favor of the U. S. No. 1 variety both in foliage resistance to curly top and in size of root produced.

[34] N. J. Giddings, senior pathologist, assisted in these tests.

[35] Acknowledgment for helpful cooperation in the location of the plots and in the analyses of samples is due the Holly Sugar Corp. and the Spreckels Sugar Co. The cooperation of the California Packing Corp. and Arthur Shauer, as growers, was also of value in carrying out the tests.

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The results from the other grower-test plantings are given in Table 27. The stand in the Manteca plot was so severely damaged by wireworms that yield records were not attempted, but the average weights per beet of the samples taken for the purpose of comparative sugar analyses afford some basis of comparison. As a means of discounting the wireworm complication the calculated yield per acre on the basis of a 100 per cent stand is likewise given. The data were obtained from 5 samples, comprising 53 roots, of the U. S. No. 1 variety, and 5 samples, comprising 57 roots, of the commercial brand. At Union Island and McDonald Island [36] the data were secured from ten 20-beet samples taken at random from each plot. The fact that the plants were selected at random rather than as normally competitive beets is disregarded in the theoretical yields calculated on the basis of a 100 per cent stand.

TABLE 27.—*Results from grower-test plantings at Manteca, Union Island, and McDonald Island, Calif., in 1931*

[Data represent averages from samples]

Locality	Date of planting	Variety	Average weight per beet	Yield per acre [1]	Sucrose	Coefficient of apparent purity	Sugar per acre: Gross	Sugar per acre: Indicated available
			Pounds	*Tons*	*Per cent*		*Pounds*	*Pounds*
Manteca	Jan. 15	U. S. No. 1	1.43	18.687	16.36	90.8	6,114	5,552
		Commercial [2]	1.05	13.721	17.40	92.2	4,775	4,403
		Difference	.38	4.966	−1.04	−1.4	1,339	1,149
Union Island [3]	Feb. 15	U. S. No. 1	2.13	27.834	17.00	78.9	9,464	7,467
		Commercial [4]	1.68	21.954	16.25	78.1	7,135	5,572
		Difference	.45	5.880	.75	.8	2,329	1,895
		U. S. No. 1	2.72	35.544	16.45	78.7	11,694	9,203
		Commercial [4]	2.025	26.462	16.75	79.6	8,865	7,057
		Difference	.695	9.082	−.30	−.9	2,829	2,146
McDonald Island	Mar. 12	U. S. No. 1	2.32	30.317	17.89	88.2	10,847	9,567
		Commercial [5]	1.97	25.743	18.23	88.3	9,386	8,288
		Difference	.35	4.574	−.34	−.1	1,461	1,279

[1] The acre yields were computed on a 100-per-cent-stand basis for sugar beets of the average weight as shown by the samples. Actual yields obtained from the McDonald Island plot were: U. S. No. 1, 19.4 tons per acre; commercial, 16 tons per acre.
[2] Dieckmann brand.
[3] The records from each of the plots on Union Island are shown separately because of wide differences in soil conditions between the 2 sets of plots. The effects of this variability are largely avoided by the comparisons as given.
[4] Schreiber & Son brand.
[5] Brand not recorded.

These tests show that in every case the U. S. No. 1 variety outyielded the commercial brand with which it was compared. In three cases the difference in the sucrose percentage was in favor of the commercial brand and in one case in favor of the U. S. No. 1 variety. Because of the limited number of samples the significance of these differences in sucrose percentage was not determined, but it should be noted that the small range is well within the sampling error. Similarly, the coefficients of apparent purity are not widely different. The

[36] It is interesting to note in the case of the McDonald Island test that for the increase in yield from the resistant plot, the grower, A. Shauer, reported receiving $36.04 more return than from the average of the 2 adjacent commercial brand plots, or an increase of $25 per acre.

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indicated-available sugar of each of the U. S. No. 1 lots was substantially larger than that of the commercial brand with which it was compared.

The results of the grower-test plantings in the central California area indicate that the U. S. No. 1 variety is distinctly superior in curly-top resistance to the commercial brands now being used and approximately equal to them in quality. Its apparently satisfactory performance under various conditions indicates that the U. S. No. 1 variety has a wide adaptability.

TESTS IN NEW MEXICO [37]

A series of tests was undertaken in 1930 and 1931 at State College and in 1931 at Las Vegas, in order to observe the performance of the U. S. No. 1 variety in comparison with commercial brands of sugar beets.

Observations from 1923 to the present time have shown that the curly-top disease occurs as practically a 100 per cent infestation in the sugar beets grown in the area near Las Cruces. It has always been so severe as to make the yield from commercial sugar beets entirely unprofitable. At Las Vegas, which is in a commercial sugar-beet-growing area, the outbreaks of the disease have been of a sporadic nature. Very little damage has been noticed in some years, whereas in other years, for example, in 1930 and 1931, the disease has been prevalent and has reduced yields sharply.

TESTS AT STATE COLLEGE

For the 1930 tests at State College, the seed used was from (1) the original U. S. No. 1 seed produced in 1929 at Twin Falls, Idaho; (2) an inbred line (90116–0) produced at Rocky Ford, Colo.; and (3) a commercial brand (Pioneer). In order to have at least one planting in the young-seedling stage at the period of the greatest influx of beet leaf hoppers, thus affording maximum exposure, plantings were made on three dates, namely, March 20, April 15, and May 15.

Each of the three kinds of seed was planted in systematically arranged plots replicated five times. Each plot was a single row 195 feet long and 22 inches from the adjacent plot. Table 28 shows the results for the three plantings of the U. S. No. 1 variety and the commercial brand used as a check.

The test demonstrated very clearly that in curly-top resistance the U. S. No. 1 variety is decidedly superior to the commercial brand used as a check. (Fig. 7.) Shortly before harvest each plant in this test was graded (0 to 6) according to the degree of curly-top injury it showed. The average of these grades represents the mean curly-top injury to the sugar-beet strain under consideration. A comparison of the averages shows decisively that in every case the commercial brand was more seriously diseased with curly top than was the U. S. No. 1 variety.

A comparison of the final stand with the original stand shows that there was a higher mortality in the commercial brand than in the U. S. No. 1 variety. For the plantings of March 20, April 15, and May 15, the resistant beet showed a mortality [38] of 20, 28, and 29.5

[37] Contributed by Harry A. Elcock. Acknowledgment is made to the New Mexico Agricultural Experiment Station for cooperation in these tests.

[38] Observation throughout the season indicated that the curly-top disease was the chief factor decimating the stand.

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per cent, respectively; whereas the corresponding plantings of the commercial brand showed a mortality of 42.7, 67, and 44.6 per cent, respectively.

FIGURE 7.—Sugar-beet tests under curly-top epidemic conditions at State College, N. Mex. Rows 19a and 22a, U. S. No. 1 variety; rows 20a and 23a, commercial (Pioneer) brand; rows 18a, 21a, and 24a, inbred line. Planted March 20, 1930; photographed September 12, 1930

TABLE 28.—*Comparison of the U. S. No. 1 variety with a commercial brand (Pioneer) of sugar beets in tests at State College, N. Mex., in 1930*

[Data represent averages from five single-row plots, each 195 feet long [1]]

Date of planting and variety	Curly-top grade [2]	Stand count of beets per plot		Original stand remaining at harvest	Yield per acre	Sucrose [3]	Coefficient of apparent purity [4]	Sugar per acre	
		June 17	Sept. 2 (harvest)					Gross	Indicated available
		Number	*Number*	*Per cent*	*Tons*	*Per cent*		*Pounds*	*Pounds*
Mar. 20:									
U. S. No. 1	3.4±0.10	95	76	80.0	8.695±0.289	13.5±0.21	84.6	2,348	1,986
Commercial (Pioneer)	4.6± .07	129	74	57.3	2.993± .246	13.5± .26	86.0	808	695
Difference	−1.2± .12	−34	2	22.7	5.702± .379	0	−1.4	1,540	1,291
Apr. 15:									
U. S. No. 1	4.0± .07	125	90	72.0	6.499± .417	13.4± .20	80.6	1,742	1,404
Commercial (Pioneer)	5.5± .03	121	40	33.0	1.119± .147	14.8± .29	85.8	331	284
Difference	−1.5± .08	4	50	39.0	5.380± .442	−1.4± .35	−5.2	1,411	1,120
May 15:									
U. S. No. 1	3.8± .11	88	62	70.5	2.728± .231	13.4± .25	80.1	731	586
Commercial (Pioneer)	4.8± .09	74	41	55.4	.946± .073	13.9± .29	83.0	263	218
Difference	−1.0± .14	14	21	15.1	1.782± .242	−.5± .38	−2.9	468	368

[1] Probable error was computed by Bessel's formula:

$$PE=0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}.$$

[2] Based on a scale graded from 0 to 6, in which 0 indicates no curly top, and 6 death of plant from curly top. The intervening grades indicate, progressively, slight, moderate, severe, and very severe effects.
[3] Determined on 3 samples from each plot.
[4] Determined by use of the refractometer, marc assumed to be 5 per cent.

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Increased resistance was shown by the U. S. No. 1 variety also in the yield of beets. In every case the yield from the resistant variety was greater than that from the commercial brand used as a check, though none was commercially profitable. These yields were based upon harvest records from measured areas, computed to an acre basis. The planting of May 15, however, produced a poor initial stand of beets, and, because of the extremely hot weather, the young seedlings were very slow in growth; the low yield of beets from this planting, therefore, was not wholly due to curly-top injury. The conditions of this test probably represent an extreme degree of curly-top exposure; under less severe conditions the yield from the U. S. No. 1 variety doubtless would be much greater.

The sucrose percentages for the 1930 experiments were determined, by the Sachs-Le Docte cold-water-digestion method, on three 5-beet samples per plot, taken at random. The average sucrose percentages for the commercial (Pioneer) brand and the U. S. No. 1 variety were the same for the March 20 planting, but for the April 15 planting the sucrose percentage was significantly in favor of the commercial brand. In the third planting (May 15), the commercial brand again showed the higher sucrose percentage, but the difference was not significant. It should be remembered that the size of beets in the two sets of samples differed markedly, since the sugar beets from the commercial brand were in nearly all cases smaller than those from the U. S. No. 1 plots.

The indicated-available sugar, determined from the three factors actual yield per acre, sucrose percentage, and coefficient of apparent purity, was in every case significantly greater in the U. S. No. 1 variety than in the commercial brand.

Two experimental tests were conducted at State College in 1931. The plots were arranged as randomized blocks. In each experiment three seed increases of the original stock of seed of the U. S. No. 1 variety, which had been tested in 1930, were used for comparison with two commercial brands. The seed of the U. S. No. 1 variety was produced in three different localities, namely, at Beaumont, Calif. (A), St. George, Utah (B), and Las Cruces, N. Mex. (C); the seed of the commercial brands used, namely, Old Type (D) and Pioneer (E), was ordinary commercial seed from Germany.

The plantings at State College were made on two different dates, namely, March 16 and April 1, in an attempt to secure high exposure to curly top by having the plants in a susceptible stage at the time of the greatest influx of the beet leaf hoppers. Because of conditions in the breeding grounds, the leaf-hopper influx was later than normal, and the curly-top infection was less severe than that of the preceding season.

Each plot consisted of four rows 185 feet long and 22 inches apart. The randomized-block arrangement for the five seed lots provided five replications of each. The plots were arranged as 4-row strips across the field in the following order (each letter representing one plot): D E C B A, C A E D B, C A B D E, D C A B E, A C D E B. The two center rows of each plot were harvested and the yield determined from the weights of all the beets in the plot. These plot yields were computed to a ton per acre basis. Determinations of sucrose percentage and the coefficient of apparent purity were made from three 20-beet samples taken at random from the center rows.

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Sucrose was determined by the Sachs-Le Docte cold-water-digestion method. The coefficient of apparent purity was determined by the refractometer, a 5 per cent marc being assumed in calculating sucrose in the juice from sucrose in the pulp.

The data from the individual plots of the 1931 test have been analyzed according to accepted statistical methods (*9*) and the results are given in Table 29. In this presentation of the data, computations have been made to determine the statistic z as a convenient measure of the significance of the test for the attribute considered. Standard errors of the means were computed [39] in all cases where the value of z as found equaled or exceeded the value of z at the 5 per cent or the 1 per cent point as given in Fisher's tables (*9*), corresponding approximately to odds of 20 to 1 or 100 to 1, respectively. From this computation a value has been found for the difference between two means necessary for significance.

TABLE 29.—*Comparison of three increases of the U. S. No. 1 variety with two commercial brands, planted March 16 and April 1, 1931, at State College, N. Mex.*

[Data represent averages from 5 plots, each consisting of 4 rows 185 feet long and 22 inches apart]

PLANTING OF MARCH 16

Variety	Curly-top grade	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre [a]	
					Gross	Indicated available
		Tons	*Per cent*		*Pounds*	*Pounds*
U. S. No. 1 increase from—						
(A) Beaumont, Calif.	2.00	13.354	14.2	75.96	3,788	2,881
(B) St. George, Utah	2.10	13.238	14.6	76.30	3,986	2,953
(C) Las Cruces, N. Mex.	2.10	13.632	14.8	78.26	4,040	3,149
Average	2.07	13.408	14.5	76.84	3,938	2,994
Commercial:						
(D) Old Type	3.29	9.275	14.9	79.26	2,759	2,186
(E) Pioneer	3.49	8.574	15.4	77.58	2,626	2,034
Difference:						
Av. U. S. No. 1—D	−1.22	4.133	−.4	−2.42	1,179	808
Av. U. S. No. 1—E	−1.42	4.834	−.9	−.74	1,312	960
z [b]	2.9995	.6367	.7379	.5271	.5958	.5552
Standard error	.0813	2.925	.4505		823	638
Standard error of mean	.0364	1.308	.2015		368	285
Standard error of difference	.0515	1.849	.2849		520	403
Difference required for significance	.1030	3.699	.5698		1,040	806

PLANTING OF APRIL 1

U. S. No. 1 increase from—						
(A) Beaumont, Calif.	2.80	12.845	14.4	73.02	3,709	2,699
(B) St. George, Utah	2.79	13.780	14.5	75.02	4,022	3,034
(C) Las Cruces, N. Mex.	2.70	13.064	15.0	75.78	3,930	2,979
Average	2.76	13.230	14.6	74.61	3,887	2,904

[a] Obtained by averaging individual plot values; hence differing slightly from the product of means given in this table.

[b] z=one-half the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z=0.5505; 1 per cent point=0.7814.

[39] Standard error of a single determination was found by extracting the square root of the variance due to error (mean square). The standard error of a mean was found by dividing this standard error by $\sqrt{n}$; in this case, the number of replications was 5. The standard error of the difference was found by multiplying the standard error of the mean by $\sqrt{2}$. The last-named number multiplied by 2 was taken as the difference required for significance between two means.

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TABLE 29.—*Comparison of three increases of the U. S. No. 1 variety with two commercial branas, planted March 16 and April 1, 1931, at State College, N. Mex.*—Continued.

PLANTING OF APRIL 1—Continued

Variety	Curly-top grade	Yield per acre	Sucrose	Coefficient of apparent purity	Sugar per acre	
					Gross	Indicated available
Commercial:		*Tons*	*Per cent*		*Pounds*	*Pounds*
(D) Old Type	3.60	8.839	14.2	73.59	2,498	1,837
(E) Pioneer	3.80	7.245	14.8	73.60	2,136	1,572
Difference:						
Average U. S. No. 1—D	−.84	4.391	.4	1.02	1,389	1,067
Average U. S. No. 1—E	−1.04	5.985	−.2	1.01	1,751	1,332
z[1]	2.8088	1.2725	.1957	.3995	1.3092	1.2981
Standard error	.0700	1.827			529	413
Standard error of mean	.0313	.817			237	185
Standard error of difference	.0443	1.156			335	262
Difference required for significance	.0886	2.312			670	524

[1] z=one half of the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z+0.5505; 1 per cent point=0.2814.

The injury from curly top in 1931, though very marked, was somewhat less than in 1930 because the invasion of the beet leaf hoppers occurred much later in the season. Nevertheless, a 100 per cent infection was present by August 15. As compared with the severity of curly top in later experimental plantings in the same field, however, neither the 1930 nor the 1931 test showed maximum injury from the disease. No significant differences in susceptibility to curly top were found among the three seed lots of the U. S. No. 1 variety. There was, however, a significant difference between the average grade of the U. S. No. 1 variety and that of each of the commercial checks in both the March 16 and the April 1 planting. (Table 29.) Of the three types, the U. S. No. 1 variety showed the least injury from curly top, and the commercial brand Pioneer showed the most injury.

In yield per acre the average of the three seed lots of the U. S. No. 1 variety was decidedly greater than that of either of the two commercial checks. (Table 29.) The superiority of the resistant variety was especially marked in the planting of April 1, where the injury from curly top was the greater. In both tests, however, the difference in favor of the U. S. No. 1 variety was significant.

In sucrose percentage the statistical analysis of the results for the planting of March 16 showed that the value of z exceeded the 5 per cent point.[40] The commercial brand Pioneer showed a sucrose percentage significantly higher than the average for the three U. S. No. 1 lots. (Table 29.) The differences between the sucrose percentages of Old Type and Pioneer and between those of the two U. S. No. 1 increases (B and C) were not significant. There was, however, a slight significant difference between increases A and C of the U. S. No. 1 variety. These results indicate a slight superiority of the commercial brand Pioneer in sucrose percentage. When analyzed statistically, the average sucrose percentages in the April 1 planting showed no significant differences among the five seed lots; the value of z was found not to exceed the 5 per cent point.

[40] The fact that the value of z exceeds the 5 per cent point indicates odds of approximately 20 to 1 that the differences shown are not due to chance alone.

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For indicated-available sugar, calculated from the three factors yield per acre, sucrose percentage, and coefficient of apparent purity, the average of the three seed lots of the U. S. No. 1 variety in the planting of March 16 exceeded by a significant amount that of each of the commercial brands. (Table 29.) In the planting of April 1 the average for indicated-available sugar of the three seed lots of the U. S. No. 1 variety was also significantly greater than that for each of the two commercial brands. In neither planting were the differences among the three seed lots of the U. S. No. 1 variety or between the two commercial brands significant. The difference in indicated-available sugar per acre in favor of the U. S. No. 1 variety over the commercial brands was greater for the April 1 planting than for the March 16 planting, doubtless because of the severity of the disease in the April planting and the marked resistance of the U. S. No. 1 variety.

The 1931 test at State College showed that under conditions of fairly severe curly top the U. S. No. 1 variety produced a crop greatly superior to commercial brands in yield and equaling or closely approaching them in quality. The results do not indicate, however, that the U. S. No. 1 variety would be commercially satisfactory in this area.

TEST AT LAS VEGAS

A test was conducted at Las Vegas, in 1931, on the farm of the New Mexico Agricultural Experiment Station,[41] which is located in the sugar-beet-growing area of that locality. In this experiment the three seed lots (A, B, and C) of the U. S. No. 1 variety used in the State College tests, an inbred line 90116–0 (D), and the commercial brand Pioneer (E) were planted in the following randomized-block arrangement: D E C B A, B D E A C, C A B D E, E B A C D. Each plot consisted of four rows 80 feet long and 22 inches apart. The yield was determined by harvesting all the beets in the two center rows. The sugar and purity determinations were made from one 10-beet sample taken at random from each plot. These samples were sent to the United States Sugar Plant Field Laboratory at Rocky Ford, Colo., for analysis.[42]

For nearly all attributes measured (Table 30), the results of this test were in close conformity with those obtained in the State College tests. The U. S. No. 1 variety was superior in curly-top resistance, as shown by comparing its average curly-top grade (2.36) with that of the inbred line 90116–0 (3.59) and that of the Pioneer commercial brand (4.00). Statistical analysis shows that the value of z for this portion of the experiment exceeded the 1 per cent point.[43] The three U. S. No. 1 seed lots were significantly more resistant to curly top than either the commercial brand or the inbred line, but showed no significant differences among themselves. If the Pioneer commercial brand be regarded as the criterion, the curly-top injury at Las Vegas was apparently slightly greater than that at State College.

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[41] Acknowledgment is made to Shelby Utz, manager of the experimental farm at Las Vegas, for planting and caring for the beets during the course of the experiment.

[42] The sucrose percentage was determined by the cold-water-digestion method, and the coefficient of apparent purity was determined from the Brix reading as compared with the sucrose reading of the expressed juice.

[43] Corresponding approximately to odds of 100 to 1 that the differences shown were not due to chance.

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Each of the three seed lots of the U. S. No. 1 variety gave significantly better tonnage than either the commercial brand or the inbred seed. The differences between the three seed lots of the U. S. No. 1 variety do not indicate significant differences in yield among themselves. In percentage of sucrose no significant differences were found.

TABLE 30.—*Comparison of the U. S. No. 1 variety (three increases) with an inbred line and a commercial brand at Las Vegas, N. Mex., in 1931*

[Data represent averages from four plots, each consisting of four rows 80 feet long and 22 inches apart]

Variety	Curly-top grade	Yield per acre	Sucrose [1]	Coefficient of apparent purity	Sugar per acre [2]	
					Gross	Indicated available
U. S. No. 1 increase from—		*Tons*	*Per cent*		*Pounds*	*Pounds*
(A) Beaumont, Calif.	2.40	13.250	14.6	82.35	3,857	3,176
(B) St. George, Utah	2.29	14.328	13.7	83.85	3,937	3,311
(C) Las Cruces, N. Mex.	2.39	12.593	14.5	85.07	3,660	3,117
Average	2.36	13.390	14.3	83.76	3,818	3,201
(D) 90116-0 (inbred)	3.59	8.003	14.3	85.50	2,291	1,953
(E) Commercial (Pioneer)	4.00	6.706	15.0	85.16	1,966	1,712
Difference:						
Average U. S. No. 1—D	−1.23	5.387	0	−1.74	1,527	1,248
Average U. S. No. 1—E	−1.64	6.684	−.7	−1.40	1,852	1,489
z [3]	1.2240	.8921	.1577	.7093	.8555	.7890
Standard error	.4213	2.488	----------	1.2785	713	616
Standard error of mean	.1884	1.112	----------	.5717	319	275
Standard error of difference	.2664	1.572	----------	.8084	451	389
Difference required for significance	.5328	3.144	----------	1.6168	902	778

[1] Determined on one 10-beet sample per plot.
[2] Obtained by averaging individual plot values; hence it differs slightly from product of means given in this table.
[3] z=one-half the difference between the natural logarithms of the variances for variety and error. The 5 per cent point for z=0.5907; 1 per cent point=0.8443.

The sugar-per-acre values (gross and indicated available) were uniformly in favor of the various U. S. No. 1 seed lots. (Table 30.) The value of z was found to exceed the 5 per cent point. No significant differences were found among the three seed lots of the U. S. No. 1 variety, but each was significantly better than the commercial brand in the yield of sugar per acre.

Close watch was kept in 1931 for any tendency of the plants to bolt. Of approximately 32,000 individual beets subjected to close observation only three beets were found that produced seed stalks in the first year of growth. This number is so insignificant as to be entirely negligible.

In the U. S. No. 1 variety, produced originally by mass selection of resistant plants, the resistant individuals appear to be in the majority. Because of the superior performance of these resistant individuals the U. S. No. 1 variety shows better results under curly-top conditions than do standard commercial brands. Readings of the degree of curly top present in hundreds of individual plants were made at State College in 1930 and 1931 and at Las Vegas in 1931. Evidence of curly top was found in every plant examined. The results obtained, therefore, are not due to immunity of certain individuals or to escape of infection. The effect of curly top in the majority of the individual plants seemed less severe than in the

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ordinary commercial beet, and this general resistance, together with the striking performance of many individuals that were outstanding in resistance, is responsible for the very encouraging results obtained. It was clear from the examination of the plots that, although a considerable portion of the beets had been killed by curly top and some that were attacked early did not reach commercial size, the majority grew well in spite of curly top.

The results seem to indicate that under New Mexico conditions there is no large or consistent difference in quality between the U. S. No. 1 variety and commercial brands.

The U. S. No. 1 variety, as judged by the 1931 tests and the general course of curly top in that area, seems to be especially well adapted to the Las Vegas district, where in some years sugar beets are produced at a profit, whereas in other years the crop, under a moderate curly-top outbreak, drops to 7 or 8 tons per acre, a yield that is probably below the cost of production. The performance of the U. S. No. 1 variety clearly indicates that under a curly-top outbreak of this type such gains in yield and sugar per acre would result from the use of this variety as to make the crop profitable instead of unprofitable.

DISCUSSION AND CONCLUSIONS [44]

The degree of curly-top resistance in the variety U. S. No. 1 and hence the measure of curly-top control, which use of this variety will assure, are clearly indicated by the studies reported in this bulletin. The results presented also afford some evidence as to the performance of this variety under conditions where curly top is absent or only a minor factor.

YIELD

TESTS IN 1930

Intensive agronomic tests on a limited scale were conducted with the U. S. No. 1 variety in 1930 in Idaho, Utah, California, and New Mexico.

In the Idaho tests, because of adverse soil conditions as well as severe curly-top injury, the U. S. No. 1 variety gave an average yield of only 5.5 tons per acre; but the commercial brand (Pioneer) used as a check averaged slightly less than 1 ton per acre.

In the Utah tests, three degrees of curly-top exposure were secured. In one field, where the exposure was due solely to the natural leafhopper infestation and where only a mild type of the disease resulted, the average yield from the U. S. No. 1 variety was 19.5 tons per acre and from the commercial brand (Schreiber S. K. W.) 14.6 tons per acre. In another field, where the plants were artificially inoculated by caging viruliferous leaf hoppers on each plant and severe curly-top injury resulted, the U. S. No. 1 variety yielded 7.6 tons per acre as compared with a yield of 2.5 tons per acre from the commercial brand (Schreiber S. K. W.). Chiefly because of the disease, a noteworthy reduction in stand took place between the time of thinning and harvest; 5.5 per cent of the original stand was lost in the U. S. No. 1 variety and 32 per cent in the commercial brand. Such drastic injury as

[44] Contributed by Eubanks Carsner and A. W. Skuderna.

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resulted in this case is rarely if ever encountered naturally under good soil and cultural conditions when the planting is made as early as advisable. A third test was made in the field where the foregoing one was conducted. In this case the plants were exposed only to the natural infestation of leaf hoppers, but distinctly more curly-top injury resulted than in the first test because of the fact that the virulent virus was introduced into this field both through the plants artificially inoculated and by the planting of a few severely diseased mother beets from the year before. From the severely diseased plants the leaf hoppers in moving about could acquire the virulent virus and carry it throughout the field. The U. S. No. 1 variety in this third test yielded 17.1 tons per acre, whereas the commercial brand (Schreiber S. K. W.) yielded 7.1 tons per acre.

The tests in California in 1930 were conducted under conditions of very light curly-top exposure. In one case the U. S. No. 1 variety gave an average yield of 23 tons per acre and the commercial brand (Old Type) yielded 20.5 tons per acre. There were only four replications in this test, and in view of the range in plot yields it is uncertain how much of the difference between the commercial brand and the resistant variety should be attributed to curly-top injury. In the other test there was only one plot of each variety and, although the commercial brand (Old Type) showed a greater percentage of cases of curly top, there was obviously no significant disease injury. The U. S. No. 1 variety yielded 18.8 tons per acre and the commercial brand yielded 20.8 tons per acre.

In New Mexico three degrees of curly-top injury were obtained by planting on three dates. A planting on March 20 gave for the U. S. No. 1 variety an average yield of 8.7 tons per acre and for the commercial brand (Pioneer) approximately 3 tons per acre. The second planting, April 15, gave a yield for the U. S. No. 1 variety of 6.5 tons per acre and for the commercial brand (Pioneer) 1.1 tons per acre. In the last planting, May 15, the U. S. No. 1 variety yielded 2.7 tons per acre, and the commercial brand (Pioneer) averaged 0.9 ton per acre.

These tests in 1930 indicate that the U. S. No. 1 variety will outyield susceptible commercial brands under all conditions when curly top is a controlling factor. This advantage of the resistant variety is often increased as the disease exposure becomes greater, but it should be noted that the U. S. No. 1 variety is strongly injured by severe exposure. The results also suggest that where curly top is not an important factor the yield of commercial brands may equal or exceed that of the U. S. No. 1 variety.

TESTS IN 1931

Further comparisons between the U. S. No. 1 variety and various commercial brands were made in 1931. Fourteen intensive agronomic tests were conducted in the four States previously mentioned. In addition to these there were 33 large-scale tests in commercial fields from which data were obtained. In each of the latter tests, known as grower-test plantings, a total of approximately 1 acre of the U. S. No. 1 variety was compared with a similar area of a commercial brand, and in most instances the planting arrangement was such as to give two or more replications.

The harvest records were secured from the grower-test plantings in essentially the same manner that the records of the more intensive

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tests were taken. For this reason and in view of the similarity in trend of the results, it will be advantageous in this discussion to consider the results of the two series of experiments together.

Most of the tests were carried out under conditions where curly top was an important factor, and those which may be so grouped will be considered first. Forty-one of the tests fall in this category, and these included a wide range in degrees of curly-top exposure. This fact is brought out by the yield records. The yield-per-acre values were calculated in all but a few instances by multiplying the average weight of the individual normally competitive beets by the appropriate factor for a 100 per cent stand for the conditions of the planting.

The comparative records for 19 tests (2 intensive agronomic and 17 grower-test plantings) conducted in Idaho show yields ranging from 8.1 to 24.4 tons per acre for the U. S. No. 1 variety and from 4.3 to 19.5 tons per acre for the commercial brands. These Idaho tests as a whole showed average yields of 14.8 tons per acre for the U. S. No. 1 variety and 10.1 tons per acre for the commercial brands.

The evaluation studies carried on in Utah included four cases in which the results were vitiated by failure of the irrigation-water supply. The results of these four tests are not included in the present discussion, but it is of interest to note that the trend of yield results is in the same direction as in all the other tests. The U. S. No. 1 variety exceeded the commercial brand in yield in each case, but in one instance the difference was probably not significant. In five other Utah tests where curly top was an important factor, the yield of the U. S. No. 1 variety ranged from 14.1 to 27.2 tons per acre with an average of 20.9 tons. The commercial brands in the same tests yielded 5.9 to 22.7 tons per acre, an average of 13.2 tons.

The California experiments in 1931 included nine tests in which curly top was an important factor influencing yields. The results at Shafter are omitted because of the fact that the yields obtained were influenced by the garden-nematode infestation of the field. Only one experiment from Bakersfield (February 10) is included, since so far as possible the results used in this general summary have been confined to those from plantings made on dates conforming to what would be a normal planting date for the locality. Repeated experience at Bakersfield has shown that March 3 is too late for commercial plantings there; hence, the results from the planting of that date are omitted. It may be noted that the March 3 planting showed an average yield of 11.9 tons per acre for the U. S. No. 1 variety and 3.9 tons per acre for the commercial brand (Old Type) used as a check. At Buttonwillow, similarly, only the results from one of the two trials have been used, since it is believed that the results from the February 12 planting are the more representative for the purposes of this discussion. It should be noted that the January 13 planting at Buttonwillow, which is omitted, gave an average yield of 22.2 tons per acre for the U. S. No. 1 variety and an average of 18.2 tons per acre for the commercial brand.

Six tests in California (three intensive agronomic and three grower-test plantings)[45] are considered as representative of the U. S. No. 1 variety growing under conditions where curly top is a factor. The yields of the resistant variety ranged from 18.7 to 30.3 tons per acre,

[45] The results from only the first set of plots from the grower-test planting on Union Island were used in this summary.

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with an average of 23.8 tons, in contrast with the commercial brands, which ranged in yield from 13 to 25.7 tons per acre, with an average of 17.3 tons.

The New Mexico plantings in 1931 included two at State College and one at Las Vegas. The planting of March 16 at State College yielded an average of 13.4 tons per acre for the U. S. No. 1 variety and 8.9 tons per acre for the commercial brands (Old Type and Pioneer). In the April 1 planting the average yield of the U. S. No. 1 variety was 13.2 tons per acre, and that of the commercial brands was 8 tons per acre. Only the results of the March 16 planting are included in the averages shown in Table 31. The Las Vegas test showed an average yield of 13.4 tons per acre for the U. S. No. 1 variety and 6.7 tons per acre for the commercial brand (Pioneer).

Six of the 1931 tests were conducted under conditions where curly-top injury was absent or else an unimportant factor. These tests were: One near Salt Lake City, Utah; 2 near Fruita, Colo.; and 1 each at Bakersfield (the January planting), Chino, and Oxnard, in California. The results of these comparisons with commercial brands afford some indication of the performance to be expected of the U. S. No. 1 variety if it should be planted in seasons when curly top does not cause serious damage. The same may be said for areas only slightly affected. The range in yields for the U. S. No. 1 variety in these tests was from 18.8 to 27.9 tons per acre and for the commercial brands from 17.3 to 26.9 tons per acre. The difference between the averages (0.5 ton per acre), as shown in Table 31, if significant at all, is probably to be attributed to the curly-top factor.

QUALITY

Because of the large number of determinations of sucrose percentage and purity made in connection with the many field tests, it has been possible to compare the quality of the U. S. No. 1 variety with that of the commonly used commercial brands.

The test in Idaho in 1930, as mentioned earlier in this discussion, was made under unfavorable soil conditions. This fact probably explains the exceptionally low sucrose percentages found. Tests of the U. S. No. 1 variety showed a higher sucrose percentage than tests of the commercial brand (Pioneer) used as a check. In 1931, sucrose percentages were determined in connection with each of the 19 field tests carried on in Idaho. In 5 cases the average sucrose percentage of the U. S. No. 1 variety was numerically lower by between 0.2 and 0.9 per cent than that of the commercial brand compared with it, and in 5 other cases it was higher by the same amounts. The general average of the 19 tests shows a sucrose percentage of 18.09 for the U. S. No. 1 variety and 18.01 for the commercial brands. The U. S. No. 1 variety showed a slightly higher coefficient of apparent purity in most cases, but the average difference was too small to be significant.

Sucrose determinations were made in connection with two of the field tests in Utah in 1930. They showed numerical differences of 0.14 and 0.6 per cent sucrose in favor of the commercial brand (Schreiber) used for comparison.

The six Utah field tests, in 1931, where irrigation water was adequate, showed in every case a higher sucrose percentage for the commercial brands used. The numerical differences ranged from 0.2 to 1 per cent, with an average of 0.6 per cent. The coefficients of

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apparent purity were not significantly different. The two tests in Colorado showed practically the same sucrose-percentage readings for the U. S. No. 1 variety as for the commercial brand (Braune Elite).

In the two California field tests in 1930, the sucrose percentage of the U. S. No. 1 variety was higher by 0.14 than that of the commercial brand (Old Type) in one case and lower by 0.8 in the other. Twelve sets of comparative determinations in 1931 showed the U. S. No. 1 variety higher in sucrose percentage in six cases and lower in six cases. The average of the differences was too small to be significant. There was no significant difference in purity.

The New Mexico tests in 1930 showed the U. S. No. 1 variety equal in sucrose percentage to the commercial brand (Pioneer) in one case and lower by 1.4 and 0.5 in the other two cases, respectively. The three tests in 1931 showed a slight but significant superiority for the commercial brand Pioneer over the U. S. No. 1 variety.

The results of the investigation seem to justify the conclusion that the average sucrose percentage of the U. S. No. 1 variety was lower by a fraction of a per cent than that of the commercial brands with which it was compared. The evidence indicates no significant difference in purity.

Since the U. S. No. 1 variety closely approaches the commercial brands in quality, it will probably show under curly-top conditions a superiority in yield of sugar per acre almost directly proportional to its superiority in yield of beets.

Table 31 summarizes the results of 6 tests under conditions where curly-top injury was not an important factor and of 32 tests where the disease was a factor of varying degrees of importance. The results under nearly normal conditions are too few to be conclusive, but they suggest that when curly top is not a factor little difference is probably to be expected between the U. S. No. 1 variety and the commercial brands used. The tabulated results also show clearly that under curly-top conditions the U. S. No. 1 variety is markedly superior to the commercial brands.

TABLE 31.—*Summary of comparisons of the U. S. No. 1 variety with commercial brands, based on tests made in Idaho, Utah, Colorado, California, and New Mexico in 1931*

Conditions	Tests	Yield per acre [1]			Average sucrose			Gross sugar per acre [2]		
		U. S. No. 1	Commercial	Difference	U. S. No. 1	Commercial	Difference	U. S. No. 1	Commercial	Difference
	Number	*Tons*	*Tons*	*Tons*	*Per cent*	*Per cent*	*Per cent*	*Pounds*	*Pounds*	*Pounds*
Curly top a minor factor or absent	6	23.8	23.3	+0.5	15.7	15.5	+0.2	7,473	7,223	+250
Curly-top injury ranging from moderate to severe	32	17.3	11.8	+5.5	17.45	17.53	−.08	6,038	4,137	+1,901

[1] Yields were computed to the ton-per-acre basis for easy comparison. In nearly all cases, the yields were computed from the average weight of beet by multiplying by a factor suitable for the row width employed in the test. They are expressed in terms of 100 per cent stands. Actual stand would need to be taken into consideration to make the yield data strictly applicable to actual yields. For curly-top conditions, it seems probable that the actual yields would be closely approached by direct application of the actual-stand factor. (See p. 22 and 29.)

[2] Obtained from general averages for yield and sugar given in this table.

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The tests reported in this bulletin have demonstrated that through disease resistance curly top as it affects sugar beets can be fairly well controlled. This fact is of more importance than is the development of a particular variety such as the curly-top-resistant variety U. S. No. 1. The utilization of this variety to secure curly-top control by disease resistance indicates the possibility of an entirely satisfactory solution of this problem.

IMPERFECTIONS IN U. S. NO. 1

The U. S. No. 1 variety is not immune to curly top. The extent to which it is injured by the disease depends on the severity of the exposure. Data have been presented which indicate this fact. Under curly-top exposure, many individual plants in the variety show conspicuous symptoms of the disease. The variety as a whole shows a degree of resistance intermediate between the susceptibility of the commercial brands and the very high resistance of certain low-sugar strains.

A more serious imperfection in the U. S. No. 1 variety is a tendency to bolt.[46] There is evidence that this characteristic is attributable to the inclusion in the U. S. No. 1 variety of the strain 905a2, which has this tendency, and possibly because of the inclusion of other strains that show the bolting tendency to a lesser degree. This tendency in the U. S. No. 1 variety will probably continue to manifest itself in practically the same degree provided full random mating occurs in subsequent generations. It seems probable, however, that through additional selection the U. S. No. 1 variety may be greatly improved with respect to bolting.

It is recognized that the resistant variety U. S. No. 1, as now constituted, is not a finished product and that it offers considerable opportunity for improvement. Under many conditions, however, its shortcomings do not preclude its use. The general consensus of opinion of all who have closely followed the tests is that utilization of this resistant variety will constitute a distinct step in curly-top control, since under all conditions but that of extreme exposure to the disease the variety gives promise of satisfactory results. On the basis of the experience reported in this bulletin, the use of this variety is recommended until a better variety can be developed from the resistant strains now in process of selection and improvement.

PLAN FOR MAKING U. S. NO. 1 COMMERCIALLY AVAILABLE

The Bureau of Plant Industry is planning to release, under proper restrictions, the U. S. No. 1 variety for use by growers in the area affected by curly top. It is estimated that there are at least 50,000 to 75,000 acres which have been used within the past few years for sugar-beet culture and which have been made marginal for sugar-beet

[46] In 1932, because of a seasonal difference, bolting in the U. S. No. 1 variety was generally more evident in the area west of the Rocky Mountains. The U. S. No. 1 variety showed 1 to 6.7 per cent bolters in locations in Idaho where in 1931 it had had less than 1 per cent bolters. A planting at King City, Calif., on Jan. 10, 1932, developed 52 per cent bolters in contrast to 5 per cent bolters in the check (Old Type). The 1931 plantings of the U. S. No. 1 variety made at four places in California from Jan. 13 to 16 developed so small a number of bolters as not to attract special notice. Replicated tests of the original selection and the first and second generation multiplications were conducted at Castleford, Idaho, in 1932. The percentage of bolters was small, ranging from 1 to 3.14.

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production by the frequent outbreaks of curly top. There is in addition the large acreage of good land under irrigation from which the sugar-beet industry has withdrawn and to which, by use of the curly-top-resistant variety, the industry may, as economic conditions justify, return. To supply the present active area of 50,000 to 75,000 acres in the affected districts where beets are now being grown requires, at the customary rate of planting, approximately 1,000,000 to 1,500,000 pounds of seed annually. To produce such a quantity of seed, at the conservative estimate of 1,000 pounds of seed per acre, would require about 1,000 to 1,500 acres.

The first difficulty to be overcome is that of securing an adequate supply of seed to plant the 1,500 or more acres for seed production, because the original quantity of seed of the selected variety was small and to make the needed increase under conditions where selection for curly-top resistance could be continued would require too much time and expense.

Under these circumstances, in order to secure a massive increase of the seed supply, it is proposed to continue the multiplication of the present seed stock without further selection. Special care will be taken, however, that full random matings shall occur within the plantings, in order to maintain the variety at its present level, if possible, without serious retrogression.

As has been stated, theoretically this seems a safe procedure and has proved practicable with other crops. The tests in 1930 were conducted with the original seed stock of the U. S. No. 1 variety and for the tests in 1931 the first multiplication of the original seed was used. The detailed data presented herein indicate that no drop in curly-top resistance, in quality, or in yield capacity occurred in the first multiplication of the original seed. There is some evidence that the second increase is essentially like the original seed and like the first multiplication of the original seed. At the Rocky Ford field station [47] an intensive field study was made of the behavior of successive increases of the U. S. No. 1 variety that had been produced without selection. A quantity of the first multiplication of U. S. No. 1 seed produced at Las Cruces, N. Mex., in 1930, was planted in the greenhouse in early October in 1930, and a crop of beet seed was produced from several hundred unthinned plants late in the winter and early in the spring. This second multiplication of the U. S. No. 1 variety, produced without selection, was compared in a replicated field test with the original seed, the first multiplication, and a commercial brand. Unfortunately, the plots suffered from a nematode attack, so that reliable yield data were not obtainable, but inspection of the plots indicated no retrogression in yields in the areas unaffected by nematodes. Comparable samples taken for sucrose analysis gave closely comparable values for the beets grown from these three seed lots (15.5, 15.6, and 15.8 per cent sucrose, respectively). No data in regard to curly-top resistance were obtainable, because of the absence of the disease at Rocky Ford, Colo. No indication of bolting was seen.

[47] These tests were conducted by G. W. Deming, assistant agronomist.

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In order to meet the present need for rapid increase of seed, on the basis of the plant-breeding experience and the preliminary tests reported, the immediately available seed stock of the U. S. No. 1 variety (about 300 pounds), which is the first multiplication of the original seed, has been devoted to increasing the seed supply by growing, without selection, a second increase. By extensive plantings this in turn is to be directly increased to many thousand pounds in the third multiplication. Thus the first seed to be used for sugar-beet production will be two generations removed from the seed stock which has now been extensively tested, and reliance for its behavior will have to be placed on the present rather limited information in regard to the results of such direct multiplications without selection.

The experimental work of the Division of Sugar Plant Investigations with this variety, however, is carried on each season with a stock of seed of the variety one year in advance of the commercial production of such seed, so that opportunity will be afforded to determine definitely the performance of the sugar beets from such seed before it is utilized on any comprehensive scale by growers.

Investigational work already reported (*11*) and in progress has shown that sugar-beet seed can be produced economically by the overwintering-in-the-field method in at least three southwestern areas in the United States, namely, Mesilla Valley in New Mexico, the "Dixie" section of Washington County and the Virgin River Valley in Utah, and the Hemet Valley and the Beaumont sections of California. The possibilities of beet-seed production by the overwintering-in-the-field method have not been investigated in other sections where the climate is adapted to it, and it is probable that other areas will be found suitable for the growing of the crop. The growing of beet seed requires some special knowledge of crop handling, fertilization, fitting of land, and care of the crop. Moreover, the market for sugar-beet seed is restricted to the sugar-beet factories concerned, which are the sole purchasers of the seed to be allotted to the growers in their respective districts.

In order to maintain and safeguard the resistant qualities from deterioration by accidental hybridization with nonresistant beets, to prevent mislabeling, and to coordinate the seed supply with a continuing breeding program, the Bureau of Plant Industry has supplied an association of interested sugar-beet companies with seed, for multiplication purposes only, of the first increase of the U. S. No. 1 variety. This provisional arrangement has been made subject to the requirement that the seed resulting be multiplied in the United States and that the designation "U. S. No. 1 variety" be restricted to lots of seed conforming to such standards and requirements as the bureau may need to impose in order to safeguard the public interest. During the introductory period the multiplications of the seed are being made under the direct supervision of the bureau. The performance of the variety under field conditions will be closely followed.

Because of (1) the limited available supply of seed of the U. S. No. 1 variety, (2) the obvious absence of a market for sugar-beet seed not produced by previous definite arrangement with the sugar companies, who constitute the sole market for it, and (3) the obligation enforced

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by all companies that beets must be grown from the seed furnished by the contracting companies, no seed of this variety is being made available for general distribution.

Under the plan of operation outlined the second multiplication of the original stock of seed of the U. S. No. 1 variety was produced in the summer of 1932. This amounted to several thousand pounds; enough of this was planted in the fall of 1932 to produce a large amount of seed in 1933 for general use in the curly-top areas for the planting season in 1934. As has been stated, the Federal experimental work in 1933 will be carried on with the type of material available for general use in 1934. If the resistant qualities and other attributes maintain themselves as expected, the U. S. No. 1 variety, when substituted for the present susceptible brands in the most severely affected beet-growing areas, should be very beneficial in relieving curly-top damage, and in those areas continually menaced and sometimes seriously damaged it should give a highly desirable assurance against excessive losses to the beet crop. Utilization of the variety in its present form is recommended with full recognition of the fact that it is far from a finished product and is being released in order to meet an emergency.

SUMMARY

The curly-top disease of sugar beets has been a limiting factor in many of the areas west of the Rocky Mountains from the time the beet-sugar industry was started in those areas. The beet leaf hopper is the only known transmitting agent of the curly-top virus, but the efforts to combat this insect have not yet resulted in adequate measures for its control.

Progress in the study of disease resistance in sugar beets as a control measure for curly top has previously been reported by several workers. This bulletin reports an important advance in the production of a resistant variety. By the combination of a number of strains selected for resistance, a variety has been produced which has a fair degree of resistance to curly top and is reasonably satisfactory in other respects. This variety has been designated U. S. No. 1.

The curly-top-resistant variety U. S. No. 1 was tested in agronomic trials, in 1930, in Idaho, Utah, California, and New Mexico and much more extensively, in 1931, in these States and in Colorado. These extensive tests demonstrated that it is markedly superior in resistance to any of the standard commercial brands with which it was compared. In sucrose and in purity it compares satisfactorily with standard commercial brands of sugar beets now in general use.

The resistant variety U. S. No. 1 has some imperfections which make further improvement desirable, but until a better variety is produced from the strains now being worked upon, it seems advisable that widespread use be made of this variety. Its use should afford a commendable degree of curly-top control.

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LITERATURE CITED

(1) ANONYMOUS
1908. THE PROBABLE ERROR OF A MEAN. By Student. Biometrika 6: 1–25, illus.

(2) ———
1925. NEW TABLES FOR TESTING THE SIGNIFICANCE OF OBSERVATIONS. By Student. Metron 5: 105–108.

(3) ———
1926. MATHEMATICS AND AGRONOMY. By Student. Jour. Amer. Soc. Agron. 18: 703–718.

(4) BROWNE, C. A.
1912. A HANDBOOK OF SUGAR ANALYSIS: A PRACTICAL AND DESCRIPTIVE TREATISE FOR USE IN RESEARCH, TECHNICAL AND CONTROL LABORATORIES. 787 p., illus. New York.

(5) CARSNER, E.
1926. RESISTANCE IN SUGAR BEETS TO CURLY-TOP. U. S. Dept. Agr. Circ. 388, 8 p., illus.

(6) CARTER, W.
1930. ECOLOGICAL STUDIES OF THE BEET LEAF HOPPER. U. S. Dept. Agr. Tech. Bul. 206, 115 p., illus.

(7) COONS, G. H., STEWART, D., and ELCOCK, H. A.
1931. SUGAR-BEET STRAINS RESISTANT TO LEAF SPOT AND CURLY TOP. U. S. Dept. Agr. Yearbook 1931: 493–496, illus.

(8) ESAU, K.
1930. STUDIES OF THE BREEDING OF SUGAR BEETS FOR RESISTANCE TO CURLY TOP. Hilgardia 4: 415–440, illus.

(9) FISHER, R. A.
1928. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 2, rev. and enl., 269 p., illus. Edinburgh and London.

(10) LOVE, H. H., and BRUNSON, A. M.
1924. STUDENT'S METHOD FOR INTERPRETING PAIRED EXPERIMENTS. Jour. Amer. Soc. Agron. 16: 60–68.

(11) OVERPECK, J. C., and ELCOCK, H. A.
1931. METHODS OF SEED PRODUCTION FROM SUGAR BEETS OVERWINTERED IN THE FIELD. U. S. Dept. Agr. Circ. 153, 22 p., illus.

(12) PIEMEISEL, R. L.
1932. WEEDY ABANDONED LANDS AND THE WEED HOSTS OF THE BEET LEAF HOPPER. U. S. Dept. Agr. Circ. 229, 24 p., illus.

(13) TAYLOR, W. A.
1929. REPORT OF CHIEF OF BUREAU OF PLANT INDUSTRY. U. S. Dept. Agr. Ann. Rpt. 1929, 39 p. [Separately paged.]

(14) TOWNSEND, C. O.
1908. CURLY-TOP, A DISEASE OF THE SUGAR BEET. U. S. Dept. Agr., Bur. Plant Indus. Bul. 122, 34 p., illus.

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THE HESSIAN FLY IN THE PACIFIC NORTHWEST

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INTRODUCTION

In the Pacific Northwest the Hessian fly (*Phytophaga destructor* Say) is known as an important wheat pest in the territory west of the Cascade Mountains and north of the Umpqua River. Although this territory produces but a small fraction of the wheat crop of the Pacific Northwest, wheat has always been one of the principal crops of the general farming districts west of the mountains, particularly in the Willamette Valley. It is estimated [1] that in 1927 this territory produced approximately 4,220,000 bushels of wheat on about 189,000 acres.

In this territory the Hessian fly is not so serious a pest as it is in many other areas. This may be attributed to the fact that the prevailing practice of late fall preparation of the land and consequent late seeding, which have been brought about by climatic conditions and the abandonment of the early-day practice of summer fallowing, have avoided infestation of fall-sown wheat in the fall. Hence Hessian-fly damage to young stands of fall-sown wheat has

[1] From data on Oregon crop production, 1927, by F. L. Kent, agricultural statistician, U. S. Department of Agriculture. The estimate given above includes western Washington, as producing 200,000 bushels on 8,500 acres (*19*).[2]

[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

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been prevented and the fields have been kept remarkably free from early volunteer wheat. Hessian-fly infestation of planted wheat has been limited, almost without exception, to that occurring in the spring.

As the Hessian fly is now well known to many farmers in this territory, numerous complaints of injury to wheat are made, especially in years when the insect is more abundant than usual. Some of the failure of wheat to fulfill expectations can doubtless be attributed to Hessian-fly injury. But this readily discernible factor is often given all the blame, whereas combinations of other factors often contribute much more to the reduction of the wheat crop than does the fly. The main factors overlooked are the weather conditions at critical periods in the growing season. Weather, of course, is an uncontrollable factor, but injury by the Hessian fly can be controlled, or at least greatly reduced. The purpose of this bulletin is to give information on methods of combating the Hessian fly in the Pacific Northwest.

The seasonal history of the Hessian fly and the factors affecting it in this territory are of considerable importance in the nation-wide study of the problem. The climatic conditions peculiar to the Pacific Northwest seem to have brought about some modification of the seasonal history of the fly as reported for eastern localities. It is believed, therefore, that the relation of these climatic conditions to the Hessian fly, as shown herein, will contribute important data on this phase of the problem of controlling this well-known wheat pest.

The effects of the environment on the important Hessian-fly parasite *Platygaster hiemalis* Forbes seem to be even more marked, as the parasite appears to have normally two generations a year in Oregon, whereas it has but one in Pennsylvania (*7*). The seasonal history and status of *P. hiemalis* and of other parasites, some of which are not known in the East, warrant further investigation of this phase of the problem.

WHEAT CULTURE IN THE PACIFIC NORTHWEST

Wheat culture in the Pacific Northwest was introduced at the Hudson's Bay Co.'s post at Fort Vancouver about 1825 (*3, p. 278*). John McLoughlin, the chief factor of this company, reported a yield of 1,800 bushels of wheat there in 1832 (*3, p. 792*) and 5,000 bushels in 1835 (*3, p. 791*). The sections of the "Oregon country" where wheat was first grown by settlers were: French Prairie (1833) (*3, p. 792*), the Chehalem Valley, Sauvie's Island, the Tualatin Plains (1843), and the Cowlitz Valley.

Soft white varieties of wheat were grown from the first. The typical wheat berry of the Willamette Valley is still soft, plump, and white, as were the kernels in a cargo said to have been rejected in New York in early days because it was believed that the wheat had swelled during the voyage (*3, p. 792*). This soft, white wheat, often weighing more than 60 pounds to the bushel (*6, p. 72; 14, p. 37*), is usually in good demand for export.

Wheat was grown continuously, sometimes alternating with oats or, after 1865, with occasional summer fallow (*8, p. 2*). Winter wheat was seeded from August to December (*6, p. 72*); usually

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earlier (August and September) (*14, p. 50*) on summer-fallowed fields than on cropped fields. Wheat was not infrequently allowed to volunteer for subsequent harvest without additional seeding (*14, p. 51*). Wheat of a true winter habit of growth was sometimes seeded in May, pastured during the year of planting, and harvested the following year (*15*). Average yields per acre up to 1869 have been variously reported (*2, 6, 14, 15*) as 20 to 30 bushels, with exceptional yields as high as 48 bushels or even more (*14, p. 45*). When wheat yields for Oregon were first reported by the United States commissioner of agriculture, there was an average yield of 18.8 bushels per acre the first seven years, 1869–1875 (*14, p. 42*). As computed from the census figures for 1880 (*25*), the average yield for the Willamette Valley counties was 15.4 bushels per acre, with a low of 12.1 bushels for Linn County and a high of 19.5 for Multnomah County. This was the low point of reported yields.[3]

With the introduction of successful clover culture in the late eighties and early nineties (*8, p. 3*), a wheat-clover rotation, with occasional alternation with oats or with oats and vetch, was generally adopted in the best agricultural districts and has prevailed to this time. Since the practice of summer fallowing has been abandoned, fall wheat is seeded, as a rule, in October or later. This practice has been brought about by climatic conditions. The rainfall in July and August is usually very scant, and most farmers now await sufficient precipitation to enable them to work the soil up into a good seed bed before seeding their fall wheat. Under this system of agriculture and with better farming methods in general, the average yields of wheat per acre have returned to approximately those of the early days, notwithstanding the activity of the Hessian fly.

HISTORY AND DISTRIBUTION OF THE HESSIAN FLY

The date of the first appearance of the Hessian fly in the Pacific Northwest has not been determined. Motley (*15, p. 352*), in 1853, said: "The Hessian fly and the weevil are not known in this country." Moseley (*14, p. 45*), in 1878, stated that "there is no insect or mildew of any kind to injure the crops of cereals in Oregon." Lang (*10, p. 550*), in 1885, said, "there were no insect depredators." The first definite record[4] of the occurrence of the Hessian fly in Oregon was made December 9, 1897, on material from Scappoose, Oreg., according to unpublished records of the Oregon agricultural experiment station. Cordley (*4, p. 26*), of that station, reported its occurrence in Washington County, Oreg., and Clarke County, Wash., in 1899.

The Hessian fly has been under more or less close observation by the staff of the United States entomological laboratory at Forest Grove, Oreg., since 1916.[5] In 1908 and 1909 some observations

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[3] United States reports include eastern Oregon after 1875. Census reports give yields by counties.

[4] Osborn (*16, p. 10*) noted the title of an article in the Oregon Naturalist for January, 1896, entitled "Potato Bug and Hessian Fly" as indicating occurrence of the Hessian fly in Oregon. This article (which Osborn did not see) was found upon examination to be a general article by A. Gains, of Vincennes, Ind., and did not refer to Oregon.

[5] The following employees, other than the authors, have worked upon this problem and have contributed much to the mass of data upon which this paper is based. C. W. Creel, who directed the investigation up to 1919; Merton C. Lane, in 1917 to 1919; James M. Langston, who assisted in the period 1916 to 1919; Sadie E. Keen, who assisted from 1922 to 1927; and T. R. Chamberlin, who assisted in 1927 and 1928.

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were made by George I. Reeves, of the Bureau of Entomology. His notes indicate that the Hessian fly was widely distributed at that time, as he found it in the lower Columbia Valley near Vancouver, Wash., and also at Albany and Corvallis, Oreg., near the center of the Willamette Valley. Before 1925 the workers at the Forest Grove laboratory found that this pest was present over all the Willamette Valley and the lower Columbia Valley in western Oregon, and in western Washington from the Columbia River to near the southern end of the Puget Sound district in King County. In 1920 (*20, p. 145*) the Hessian fly was discovered on the Saanich Peninsula of Vancouver Island. In 1926 it was reported by workers at the Oregon agricultural experiment station from northern Douglas County in the Umpqua watershed, and in 1927 the authors found infested wheat near Yoncalla in Douglas County. In the same year wheat infested by the Hessian fly was found in the upper Hood River Valley near Parkdale, Oreg. In 1932 the Hessian fly was found to be present from Seattle north to the Canadian boundary. This wheat pest has never been found east of the Cascade Mountains in either Washington or Oregon. Its known distribution in the Pacific Northwest is illustrated in Figure 1.

EXPLANATION OF TERMS

In view of the fact that "brood" and "generation" have been used by entomologists in more than one sense, it is thought best to define these and other terms as they are used in this bulletin.

"Generation" is used in its usual biological sense as a term for a body of Hessian flies of the same genealogical rank or remove from an ancestor. A generation begins with the eggs and is considered complete when the last living form of that generation becomes adult.

"Brood" is a term applied to a group of individuals of an immature stage of the fly of approximately the same age and present at approximately the same time.

"Emergence" is a term applied to the appearance of a number of Hessian-fly adults during approximately the same period. The emergences of regular occurrence in this section are called "the first spring emergence," "the second spring emergence," and "the fall emergence." Emergences which rarely occur are termed "supplemental emergences" and may occur either in the summer or in the fall or in both. The offspring of flies of each emergence constitute a brood of corresponding nomenclature.

"Young tiller" is a term applied to a young wheat shoot the nodes of which are not yet apparent.

"Culm" is a term applied to a jointed wheat stem which shows well-defined internodes.

"Fall-sown wheat," "winter-sown wheat," and "spring-sown wheat" are terms applied to wheat seeded during the indicated season without regard to the habit of growth. The mild winter climate of western Oregon usually permits seeding of varieties of wheat of a spring habit of growth in the fall and winter, and this is a common practice. Most of the wheat sown in the territory under discussion in the fall and winter during the progress of this investigation was of the spring habit of growth. An increase has recently occurred in the acreage seeded to the true winter wheats

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in this territory. This is especially true of such varieties as Wilhelmina (White Holland) and White Winter, but many of the wheat growers in the northern end of the Willamette Valley still plant wheats of the spring type.

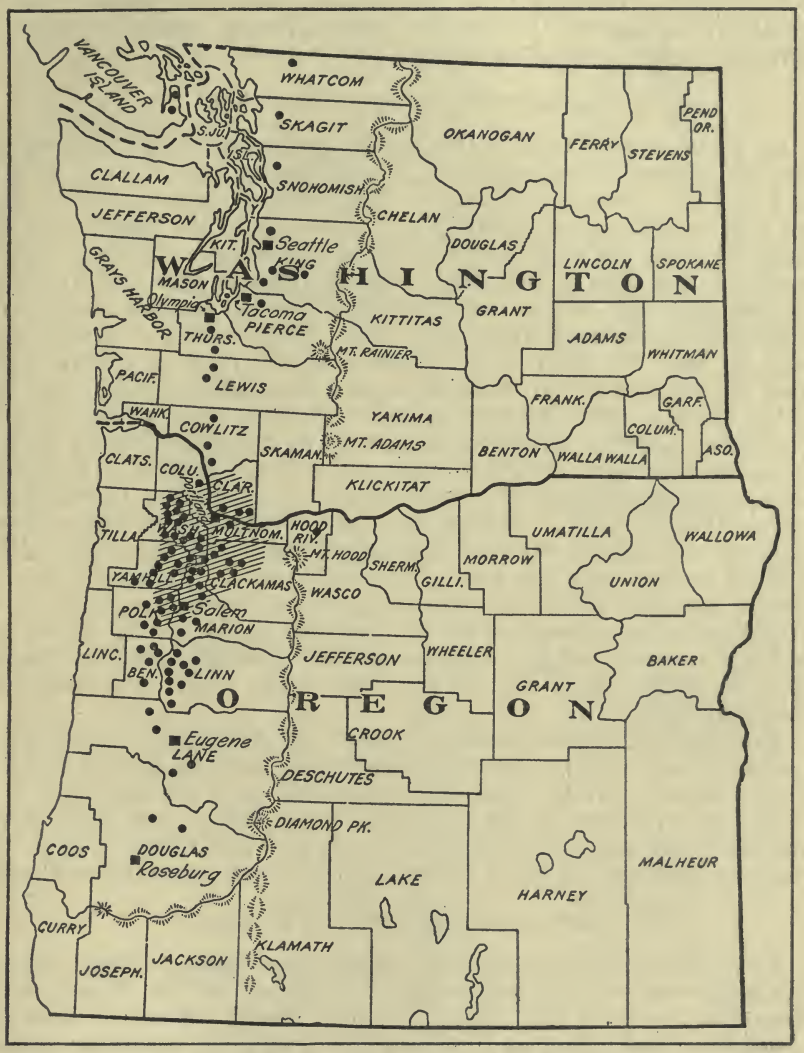

FIGURE 1.—Distribution of the Hessian fly in the Pacific Northwest. Dots represent localities where the fly has been found; shading represents sections most heavily infested

LIFE HISTORY AND HABITS OF THE HESSIAN FLY

MATING

The delicate mosquitolike flies of *Phytophaga destructor* mate soon after emergence from the puparia. M. C. Lane made some interesting observations at Forest Grove on the breeding habits in cages in 1917. He noted that the males are quick to locate fe-

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males. In one instance, in a cage 3 feet square, a male was observed to enter the mouth of a small glass vial from which the observer was trying to coax a female. Free males in the field are attracted to females in wire-screen cages. The act of mating takes from 10 to 20 seconds. One male was observed to mate with three different females in one day. In another case a female mated twice with different males in rapid succession.

OVIPOSITION AND HATCHING OF EGGS

An hour or two after mating, the female begins active oviposition and exhausts her quota of eggs and dies in a short time, usually in 1 or 2 days, rarely 3, in cages. The small elongated reddish eggs are laid on the wheat leaves (fig. 2), usually in the grooves on the upper surface, but they may be laid on the smooth undersurface or, rarely, on the stem of the plant. The number of eggs laid by single females in cages varies considerably. The maximum number recorded by Lane at Forest Grove was from a female placed in a cage on May 17, 1917. This female laid 329 eggs in a little more than 24 hours and, on dissection, was found to have 32 eggs left in her ovaries. This indicated a capacity of 361 eggs for this female. The same observer secured a maximum of 280 eggs from a female of the fall emergence (which came out on September 28, 1917), and 159 eggs from a female of the second spring emergence (which came out on June 28, 1917). McConnell (*12*), working in southern Pennsylvania, has shown that the egg-laying ability of the female Hessian fly varies with the size of the individual. He found by dissection that the actual number of eggs per female ranged from 33 to 464, with an average of 287 for females of the spring emergence and 233 for those of the fall emergence. Unmated females appear to be sluggish. They lay but few eggs before death and these eggs fail to hatch.

The hatching period seems to depend largely on the temperature. In early May and in late September eggs hatched in five days at Forest Grove. Field observations indicate that the egg period is considerably longer in the cool weather of March and early April and probably appreciably shorter in June. McColloch (*11, p. 25*) recorded extremes of 4 and 12 days in a screened insectary in Kansas.

LARVAL DEVELOPMENT AND PUPATION

The young larvae, faintly red on hatching from the egg, migrate in the grooves of the wheat leaves to points beneath the sheath, either near the crown of the plant (when on young tillers) or near the nodes of culms. In rare instances they establish themselves almost midway between nodes and apparently develop successfully. When crowded on young tillers and culms, they may spread out over a considerable area on the plant stems. When once settled against the stem of the plant, the larvae are not known to move. The period of growth is variable—from three to six weeks—and is dependent, to a large degree, upon the temperature, although probably the quantity and quality of the food absorbed are also important factors. When the larvae have attained their growth they are whitish, with a glassv luster.

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Soon after full growth has been attained the skin of the larva gradually becomes hardened and leathery and separates from the body. Inside this skin, according to Marchal (*13, p. 20*), the molted

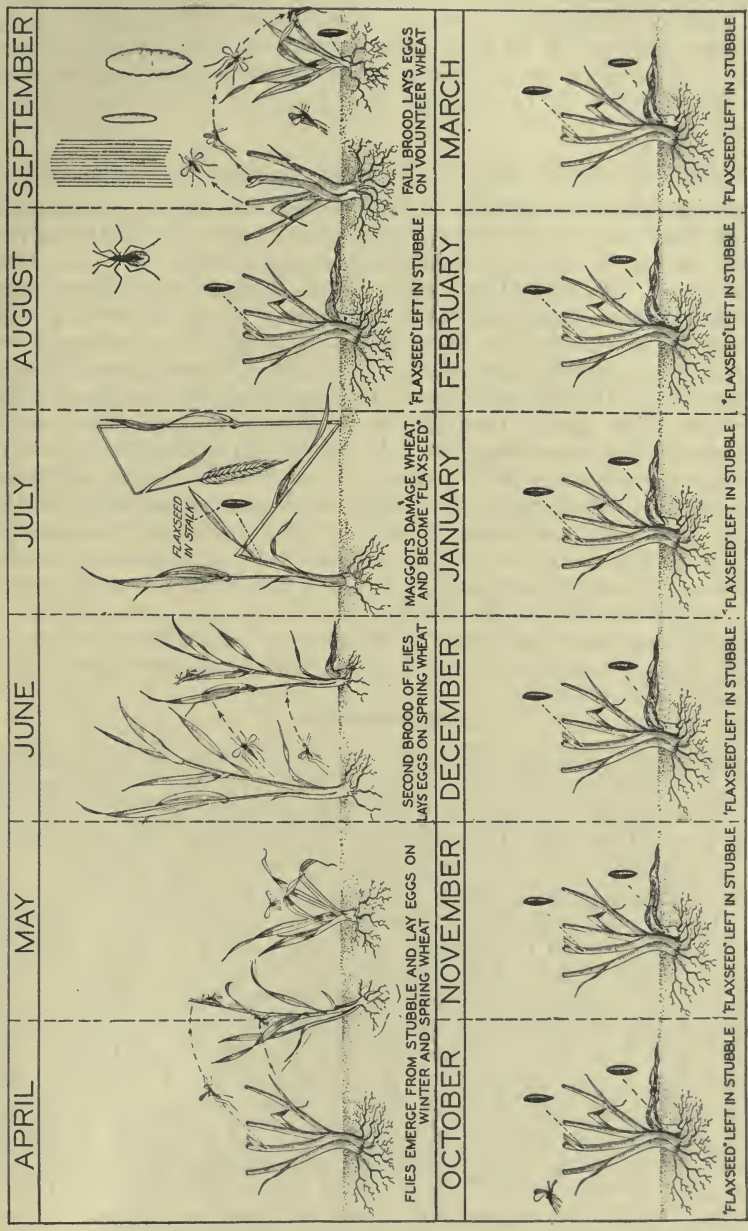

FIGURE 2.—Seasonal history of the Hessian fly in the Pacific Northwest

larva spins a thin silken lining, reversing itself during the process. The puparium thus formed is a dark brown, seedlike object about three-sixteenths inch long, and has been appropriately termed the "flaxseed." (Fig. 2.)

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The nonfeeding larva may remain within the puparium for an indefinite period. If weather conditions are favorable some of the larvae pupate soon after the formation of the puparia and in a short time emerge as flies. Others remain as larvae to pupate and emerge later, perhaps in a year or more. The duration of the pupal period in September is about 12 days. Field observations indicate that this period is dependent largely upon the temperature, as it is longer in early spring than it is in May and June or in the first part of September.

SEASONAL HISTORY AND ITS RELATION TO WEATHER CONDITIONS

Since 1917 the seasonal history of the Hessian fly has been studied through field observations, including systematic periodical counts of various stages, within a 10-mile radius of Forest Grove and, less regularly, in other localities in western Oregon and Washington. More detailed observations were made at Forest Grove on wheat plots seeded at intervals all through the season. In conformity with the practice of cooperative observers of the United States Weather Bureau, climatological data have been recorded by the Forest Grove laboratory since 1916. In addition to these standard Weather Bureau records, the percentage of relative humidity has been recorded by a hygrograph since 1919. Observations on the stages of Hessian flies occurring on wheat under field conditions, especially the first and last appearance of each stage, have been plotted for each year on tables in which each month is divided into quarters large enough for placing identifying symbols in four positions in each quarter. These tables, which are too complicated to print, have enabled the writers to correlate, to a fairly close approximation, the seasonal history with the major climatic factors, which are averaged for each quarter of a month.

OVERWINTERING

Hessian flies pass the winter as larvae in puparia on stubble, on volunteer wheat, and on wheat seeded in September, if any is available. The puparia on young wheat tillers killed by fall infestation of the fly may, on the disintegration of the plant material, become part of the débris at the surface of the soil. The puparia in the stubble, containing unemerged Hessian flies, are mostly of the spring brood, the offspring of flies of the first spring emergence. Examination of puparia from the stubble of wheat seeded in May, 1919 (and therefore infested by the second spring brood, the progeny of flies of the second spring emergence, only) showed, on October 27, 1919, only 5 per cent of prospectively overwintering larvae in the puparia that contained or had contained living unparasitized Hessian flies. At the same time, puparia from the stubble of a field seeded in March, 1919 (and therefore infested by both spring broods but principally by the first spring brood), showed 59 per cent of prospectively overwintering larvae in the puparia that were not parasitized. These are the "holdovers" that failed to produce flies for the fall emergence in the preceding September and October. These holdovers at times comprise more than 50 per cent of all puparia that have survived parasitization and mortality from other causes. In years of scant precipitation in September these holdovers are the prin-

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cipal source of flies of the first spring emergence, as was notably the case in 1929–30, when a mere trace of the fall emergence was found and that after the middle of October, 1929. In years of normal or excess precipitation in September and October there usually is a heavy infestation in volunteer wheat and in any wheat seeded in September, by the progeny of flies of the fall emergence. This was the case in 1920.

FIRST SPRING EMERGENCE

In the spring, the overwintering larvae begin to pupate in the puparia when the temperatures approximate a mean of about 45° F. Temperature appears to be the princial factor stimulating pupation at this time, as the rainfall and relative humidity are relatively high at this season. Some incipient pupae have been found as early as February (on February 14, 1920, after a mean of 46.7° F. in the last week of January, and on February 28, 1921, when the mean was 47.9° for the preceding 7-day period), but few are able to attain complete formation of the adult before the middle of March in years of an early spring, or before mid April, or even the end of April, in backward seasons. It is seldom that flies of the first spring emergence are on the wing in numbers before April. The mean temperature approximates 50° at the time when flies of this emergence are abundant. In the Pacific Northwest the first spring emergence is sometimes prolonged, or even broken up into well-separated fractions, by cold weather in March or April. In some years such conditions have produced very marked intervals in the development of the resultant brood. In one such case in 1919, progeny of the early flies of the first spring emergence produced a numerous and early flight of flies of the second spring emergence in early June, which occasioned serious damage to spring wheat in some localities. The cool spring of 1920 prolonged the first spring emergence over a period of eight weeks. Weather favorable to an early and continuous spring emergence leads to heavy infestation in fall-sown wheat, especially in late-sown fall wheat (*18*), and in wheat seeded in March. When the weather is favorable to a large second spring emergence following such an infestation, all wheat becomes more heavily infested than usual. This was the case in 1926, when the mean temperature for March was higher than the normal for April, and that of April higher than the normal for May. When the first spring emergence has been delayed or unduly prolonged, and the second spring emergence is so late as to be a negligible factor, there usually is little damage to fall-sown wheat. Such appears to have been the case in 1920 when, although the Hessian fly was more abundant than usual, the crop yields were above normal. For some unknown reason, flies do not emerge from all puparia of the same age at the same time, although apparently exposed to exactly the same conditions. Therefore, even under favorable conditions, the first spring emergence extends over a period of three weeks or longer.

SECOND SPRING EMERGENCE

The progeny of flies of the first spring emergence (the first spring brood) are located as larvae at the base of the young tillers on fall-

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sown wheat, winter-sown wheat, and spring-sown wheat and near the lowest nodes of the culms in fall-sown wheat. They develop to full-grown larvae and form puparia in from three to six weeks. Larval development is hastened by warm weather, as was the case in 1926, when it required but three weeks; or retarded by cool weather, as in 1920, when it was extended to six weeks. A part of the larvae in the puparia transform to pupae and emerge as flies of the second spring emergence. The number that develop to flies at this time appears to be somewhat dependent upon the precipitation while they are in puparia. The second spring emergence usually occurs in June and is early or late, according to the rapidity of development of the larvae and the time of precipitation. The earliest record for this emergence is May 13, 1926, a very exceptional year because of high temperatures in March and April. The latest records for the appearance of the first flies of this emergence are June 21, 1920, and June 30, 1922. The resultant second spring brood (fig. 2) is capable of causing serious damage, especially to spring-sown grain, in favorable years. Such an instance was found at Forest Grove in 1919 and 1926 and at Pleasant Hill, Lane County, in 1921. On the other hand, in years when the precipitation in June was scant the second spring brood was very small.

The authors' records show that most of the flies of the second spring emergence come from puparia of the first spring brood, but some of them come from overwintered forms in the stubble, having failed to emerge earlier. Cage experiments carried on by Lane in 1917 with single mated females showed that flies were produced in the latter part of June and early July by a large percentage of the first spring brood that survived to the puparial stage, although some were still larvae in puparia in late December. In a field of wheat seeded in February, 1921, at Pleasant Hill in Lane County, Oreg., 66 per cent of the puparia of the first spring brood contained pupae or had produced flies by May 28.

SUPPLEMENTAL EMERGENCES

Unusually heavy precipitation in July or early August brings out a suplemental emergence, as in 1918. This rarely occurs and is of of no importance in the Pacific Northwest. That some of the second spring brood may mature at once and produce flies is shown by the finding of an empty puparium and two pupae on July 26, 1920, on wheat seeded in May and infested by the second spring brood only. In 1926, 17 per cent of the puparia on wheat which had been seeded on May 13, and which was infested by the second spring brood only, were empty when examined on July 27. Further indications of emergence and continued propagation by flies after the second spring emergence and before the regular fall emergence are shown by the records of a plot of wheat seeded on July 29, 1918, after a rain of 0.95 inch that occurred between July 22 and 26. Considerable numbers of eggs were found on this plot on August 12. The resulting larvae were full grown on August 27. The first puparia were found on September 7, and three pupae and two puparia from which adults had emerged were found on September 26, at the time of the regular fall emergence from infested wheat stubble.

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FALL EMERGENCE

A considerable percentage of the first spring brood remain as larvae in the puparia during the summer. The greater number of the second spring brood, many of which are near the nodes of the culms, also aestivate (as larvae) in the puparia. Stimulated to activity by the first heavy rain (0.5 inch or more) in the early fall, many such aestivating larvae pupate in the puparia and emerge as flies of the fall emergence, beginning approximately 12 days after the rain. In the Pacific Northwest this fall rain may occur in late August, in early September, or after the middle of September. In years of scant precipitation in September there is seldom very much volunteer wheat up in time for the flies of this emergence to oviposit on it, and the number of flies may be small and may emerge for only a short period. In the most heavily infested districts of western Oregon this emergence is of practically no economic importance, in so far as crop damage is concerned, because of the customary late seeding. Heavy frosts or low mean temperatures usually bring the fall issuance to a close about the middle of October. The larvae in puparia that fail to produce flies in the fall pass the winter in this form. There are often large numbers of these.

When the fall emergence has been early, and when the temperatures in October and the precipitation at the time the resultant brood form puparia have been higher than normal, a small supplemental fall emergence may take place after the middle of October. This sometimes happens in the Middle West. There have been no very definite indications of such emergence in the Pacific Northwest during the course of the present study. Meager traces of a supplemental fall emergence are indicated by records of eggs on October 30, 1925, October 19, 1926, and October 21 to 29, 1927. It is possible that part of this small emergence represents progeny of flies of the first fall emergence. A well-marked supplemental fall emergence is apparently very rare in the area under discussion.

NUMBER OF GENERATIONS

The number of generations that occur annually is undetermined, as the offspring of the flies of no one emergence (and of no individual female) develop to adult flies at the same time. An indefinite percentage of each brood is always retarded in the puparial stage. It is, therefore, possible that no one generation is completed within the course of one year. However, previous writers have noted several partial generations in one year. Marchal (*13*) and McColloch (*11*) have reared from five to six partial generations in one year under controlled conditions. The authors have found indications that at least three partial generations usually occur in western Oregon in the field. The adults of these generations combine to form parts of the following emergences: Second spring, supplemental, and fall emergences of the same year; and the first spring emergence of the following year.

The laboratory and field observations made in this study agree with those of McColloch (*11*) in indicating that temperature and moisture, while of primary importance, are not the only factors

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affecting pupation and emergence. In the field, puparia from the same location on the plants and, presumably, of the same brood, have produced flies at widely differing dates of emergence. The junior author kept a vial containing puparia collected on June 26, 1926, regularly moistened (except from November 19, 1926, to March 11, 1927, when they were stored in a cave of uniformly high humidity), and from these secured the ordinary fall emergence from August 4 to September 9, 1926. Yet one female Hessian fly issued from this material as late as June 13, 1927. McColloch (*11*) has observed that Hessian flies issued from material kept for four years under outdoor laboratory conditions. Such delayed emergence acts as a safeguard in perpetuating the species. It also permits transportation between regions that are widely separated and probably accounts for the wide distribution of the species during a period when human transportation facilities were much slower than now.

The factors involved in these seemingly irregular reactions to temperature and moisture on the part of the Hessian fly in the puparium are unknown. They may have to do with individual nutrition and development, with consequent variations in the ratio of fat to water in the larval tissues, or with heredity. It is also possible that some slight variation in the chemical or physical structure of the puparial envelope may render some puparia more permeable to moisture than others.

INJURY AND ECONOMIC IMPORTANCE

Hessian-fly larvae feed by sucking the juice from the tissues of the stem of the wheat plant. As a result of this feeding, the tissues of young and tender tillers become abnormal at the point of attack and eventually die. Wheat infested, before jointing, by the Hessian fly exhibits a characteristic stunted appearance. The leaves are broader, less spreading, and of a darker green color than those of healthy plants. On stems that have begun to form joints before they are attacked by the maggots the injury is less obvious and consists of a weakening of the culms at the points of attack. This weakening of headed culms causes direct loss in grain through the fallen, or lodged, wheat not gathered by the binder or combine. There is also direct loss of grain, owing to insufficient nourishment of the kernels, as the feeding larvae interfere with the supply of sap to the wheat heads. In severe infestations this form of injury causes shriveled grain that reduces the grade.

INFESTATION OF VOLUNTEER WHEAT

Volunteer and second-growth wheat plants often become very heavily infested in the fall. On September 26, 1917, M. C. Lane counted 277 eggs on one leaf of a volunteer wheat plant. The junior author counted 146 larvae on five tillers of one stunted second-growth plant on October 11, 1919, in a field of late-sown spring wheat. Such infestations, while of course fatal to the affected tillers, cause no direct economic loss in so far as the grain crop is concerned. However, the pest is carried over winter in this manner and is thus enabled to infest planted wheat in the spring.

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INFESTATION OF FALL-SOWN WHEAT

Wheat seeded in August and September is very likely to become infested by the Hessian fly in the fall, and this usually causes considerable reduction in stand. It was noted that a field of wheat seeded about September 15, 1920, had the stand thinned approximately 25 per cent by an infestation that had killed many tillers and whole plants. In addition to this, the infested plants that had sufficient vitality to produce new tillers were greatly retarded, the new tillers that developed by December 17 being very small. On a wheat plot seeded August 11, 1922, and sampled by the linear-foot method (taking 10 separate linear feet) in January, 1923, 20 per cent of the young tillers out of a sample of 266 were found to be infested and dead, and of a sample of 211 tillers taken from a plot seeded on September 1, 8 per cent were in a similar condition. However, the soil of these plots was unusually fertile, and the wheat tillered freely after the infestation, more than compensating for those killed. Fortunately, in the Pacific Northwest fall-sown wheat is very rarely seeded early enough to become infested in the fall. Climatic conditions have led to the adoption of a general practice of seeding wheat in October or later.

Fall-sown wheat, if seeded early enough to get a good start before cold weather sets in, usually makes enough growth before the spring emergence of the Hessian fly to escape serious injury. When flies infest fall-sown wheat in April and May, their progeny attack the young tillers and the internodes of culms. The small tillers are killed before heading, but there appears to be a considerable mortality of these tillers at this time from other causes, as Packard (*17*) has noted. By the time of the second spring emergence such wheat is usually so far advanced as to be unattractive to the flies.

INFESTATION OF SPRING-SOWN WHEAT

Spring wheat, if seeded early enough to become infested by both spring broods of the Hessian fly, is sometimes considerably injured. Very late fall-sown (*18*) or winter-sown wheat is comparable to early spring-sown wheat in this respect. Late spring seedings of quickly maturing varieties of wheat sometimes escape any considerable degree of infestation, except in years of a heavy second spring emergence. Spring wheat is injured by a thinning out of the culms, owing to the death of tillers that might have headed had they not been infested before jointing; by the lodging of infested culms; and by the malnutrition of kernels, caused by the feeding of the larvae near the nodes of headed culms. Damage to spring-sown grain by the second spring brood was quite serious in 1919 and 1921. A field of wheat seeded in March, 1919, near Forest Grove showed, by the linear-foot count, an increase in infestation of 46 per cent of the plants and 40.6 per cent of the tillers and culms attributable to the second spring brood. The numbers of Hessian-fly forms found in 10 separate linear feet of drill row taken at random increased from 27 to 347. The heavy infestation resulting from the combination of the two spring broods caused an estimated reduction in yield of 7 bushels per acre, and the wheat was marked "Grade 3" because of

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shriveled grain.[6] In a field of wheat seeded in late February near Pleasant Hill, in Lane County, Oreg., in 1921, the second spring brood caused an increase of infestation amounting to 23 per cent of the plants and 19 per cent of the young tillers and culms. In the counts of 10 separate linear feet in this field the number of Hessian flies in all forms increased from 127 to 757.

ESTIMATE OF LOSS

The actual loss caused by the Hessian fly is difficult to estimate. Usually only young tillers are killed outright, and early fall-sown wheat on fertile soil produces a superfluity of these. This loss of tillers would be less likely to be compensated in the case of spring-sown wheat and winter-sown wheat. The principal loss of grain in the Pacific Northwest is probably owing to lodged culms and light heads on infested culms. In severe infestations where more than 50 per cent of the culms are affected the loss on fertile soil may amount to 6 to 8 bushels per acre, although the average loss, even in years of Hessian-fly abundance, is probably less than one-half as much. The grade of the wheat may also be reduced, and lower prices result. Most of the wheat acreage in the districts in Oregon most heavily infested by the Hessian fly is usually fall-sown. However, in some years there is a considerable acreage of winter-sown and early spring-sown wheat, both of which may be seriously injured by the fly.

TABLE 1.—*Relation of infestation by the Hessian fly to yields of wheat in Washington County, Oreg.*

Year	Average infestation by the Hessian fly in—						Average yields per acre	
	Winter-sown and spring-sown wheat		Winter-sown wheat [1]		Spring-sown wheat		Winter-sown wheat	Spring-sown wheat
	Plants	Young tillers and culms	Plants	Young tillers and culms	Plants	Young tillers and culms		
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Bushels*	*Bushels*
1920	49.5	24.5	46.7	23.7	55.9	27.3	28.0	25.9
1921	29.7	17.9	34.9	22.0	17.6	8.3	25.0	20.0
1922	23.9	10.8	29.1	12.1	18.6	9.6	22.0	12.0
1924	35.0	17.8	35.0	17.8	(2)	(2)	[3] 25.7	----------
1925	34.7	16.1	(4)	(4)	34.7	16.1	----------	25.0
1926	76.3	41.2	78.0	41.2	72.2	41.0	25.0	18.0
1927	24.4	8.9	20.3	7.3	30.6	11.2	25.0	20.0
1928	13.5	5.4	4.9	3.4	17.1	7.4	27.0	20.0

[1] Wheat seeded in fall and winter.
[2] Spring wheat near failure; no counts made.
[3] Both winter and spring wheat.
[4] Fall-sown and winter-sown wheat killed by December freeze.

The average percentage of infestation by the Hessian fly was determined by making counts in representative fields in Washington County. The average percentage of infestation for each year was then compared with the estimated final yields for that county as given out by F. L. Kent, agricultural statistician of the United States

[6] This estimate was arrived at by comparison with yields on fields which were seeded near the same date on similar land but were much less severely infested by the Hessian fly. Hence the reduction in yield can not be attributed with certainty to the fly.

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Bureau of Agricultural Economics for the years 1920 to 1922, and 1924 to 1928. (Table 1.) No readily discernible correlation of average yields with Hessian-fly abundance is evident. It is obvious that other factors, fully as important as this pest, affect the yield of wheat in western Oregon. Doubtless the effect of Hessian fly infestation on wheat yields could be shown if records of data on the Hessian fly and other factors that affect yield were available for a long series of years.

HOST PLANTS OTHER THAN WHEAT

BARLEY AND RYE

Barley is often infested by the Hessian fly but usually less than wheat. A field of barley near Forest Grove, seeded in June, 1919, showed 20 per cent of the plants and 10 per cent of the young tillers and culms infested when examined on July 8. Wheat seeded on the same farm at about the same time showed 59 per cent of the plants and 25 per cent of the young tillers and culms infested on July 8.

Rye also becomes infested, but no infestations approaching those in wheat have been observed. As rye is rarely grown for grain in western Oregon, no counts have been made on that crop.

AGROPYRON REPENS (L.) BEAUV.

On October 25, 1909, G. I. Reeves found a species of Agropyron near Vancouver, Wash., infested by the Hessian fly. On December 31, 1919, the junior author found large numbers of Hessian-fly puparia on a species of Agropyron at Kelso, Wash. While on a second visit to Kelso on June 14, 1920, he made a thorough search of this grass and found only two puparia.

On November 5, 1929, near Vancouver, Wash., George I. Reeves and the junior author found scattering plants of couch grass (*Agropyron repens* (L.) Beauv.[7] in wheat stubble where no volunteer wheat had yet appeared because of a deficiency of rainfall in September and October. These plants were heavily infested with partly grown larvae. On careful examination of material collected at this time only one puparium was found. From this material adult flies indistinguishable from *Phytophaga destructor* were reared in early April, 1930. These flies were kept in cages and allowed to oviposit on *A. repens* and on young wheat. Where both wheat and couch grass were available in the cage at the same time, the flies showed a decided preference for wheat. Flies, the progeny of adults from *A. repens*, were reared in early June from both couch grass and wheat. Hessian flies that emerged from puparia collected from wheat stubble also produced offspring on *A. repens* in cages. Flies, the progeny of flies of couch-grass origin, but reared on wheat, were placed on *A. repens* and again produced offspring on this grass. A few males reared on couch grass were mated with virgin females that emerged from puparia taken from wheat stubble. Mating was successful, and progeny were produced by these crosses.

It is possible that *Agropyron repens* may be of some importance as a host plant for the fall brood of Hessian flies in some localities

[7] Determined by A. S. Hitchcock, of the Bureau of Plant Industry, U. S. Department of Agriculture.

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where volunteer wheat or early-sown fall wheat are not available at the time the flies of the fall emergence are out. However, as many Hessian flies survive the winter as larvae in puparia on wheat stubble, when the rainfall in autumn is insufficient to bring up volunteer wheat, the fall brood on *A. repens* may not contribute very much to the number of flies in the first spring emergence of the following year.

CLIMATIC FACTORS

Climatic conditions have a potent influence upon the Hessian fly. Precipitation and relative humidity are probably the most important climatic factors, although temperature, in relation to these, is also of great importance.

EFFECT ON DISTRIBUTION

No occurence of the Hessian fly has been recorded in areas of the Pacific Northwest shown by Weather Bureau records (*5*, *21*, *22*, *23*, *24*) to have an average rainfall of less than 35 inches, except at Sidney, British Columbia (*5*), where the average annual precipitation is 27.7 inches; and the sections where the highest percentages of infestation are found year after year have an annual rainfall of 40 inches or more. However, as the Hessian fly is found in sections of the Middle West and of California and at Sidney, British Columbia,[8] where the average annual rainfall is less than 35 inches, it is probable that the time of precipitation and of high relative humidity in relation to effective temperature are determining factors in its distribution. The infested territory in Kansas receives most of its precipitation (18 to 30 inches) in the wheat-growing season (April to September), when the Hessian fly, if present, would be active (*9*). On the other hand, in the portion of California infested by the Hessian fly (*17*) temperatures are high enough for fly activity in February, March, and April, when the average rainfall is 7 to 14 inches. The great dry-land wheat-growing area of the Pacific Northwest has but 3 to 9 inches average precipitation in the period April to September, when temperatures are high enough to permit Hessian-fly activity.

McColloch (*11*, *p. 60*) has shown that in Kansas a relative humidity of more than 60 per cent is necessary for the sucessful hatching of the eggs and subsequent establishment of the young larvae beneath the sheath. This factor alone is probably sufficient to prevent the establishment of the Hessian fly as a wheat pest in the great dry-land wheat districts of eastern Oregon, eastern Washington, and Idaho, where the air is relatively dry except for some damp periods in winter (*23*, *24*). On the other hand, the humidity at Forest Grove, Oreg., a locality typical of the area west of the Cascade Mountains where the Hessian fly is most numerous, is relatively high in the spring and fall, as well as in winter, and is occasionally high for certain periods in the summer months. The mean monthly relative humidity at Forest Grove probably never falls below 60 per cent, even in the driest months of the summer, as 67 per cent is the average mean for July and August. Data of the United States Weather Bureau

[8] Sidney, British Columbia, is on the Puget Sound shore of Vancouver Island where the humidity is uniformly high.

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(*23*, *24*) for Baker, Oreg., and Spokane and Walla Walla, Wash., while not exactly comparable with those for Forest Grove, Oreg., indicate that the average mean relative humidity at these places (all east of the Cascade Mountains) would fall below 60 per cent during the period April to September, when the Hessian fly would be active. The data for the southeastern shore of Vancouver Island at Victoria (Gonzales Heights), British Columbia (*5*) (where the lowest monthly average of the mean relative humidity is 73 per cent, for June), show that the mean relative humidity is above 70 per cent in every month of the year, although the average annual precipitation is only 27.5 inches.

EFFECT ON EMERGENCE

Lack of moisture at critical periods stops the issuance of the flies; therefore, the periods of emergence are cut short, and the numbers of resulting offspring are greatly reduced. This is sometimes the case with the second spring emergence and nearly always with the supplemental, or summer emergence. Occasionally the fall emergence is either greatly delayed in the time of its issuance or restricted by lack of precipitation.

McColloch (*11*, *p. 58*) states that temperatures below freezing are fatal to the adult flies. In Oregon late frosts frequently interfere with the propagation of the Hessian flies during the flight of the first spring brood. Heavy frosts and low mean temperatures usually bring the fall emergence to a close about the middle of October.

EFFECT ON SUMMER MORTALITY

There is some indication that the prolonged dry periods characteristic of the Pacific-coast climate, usually occurring in July and August but occasionally beginning in June and extending well into September, cause a considerable mortality of Hessian-fly larvae in the puparia. Packard (*17*) has noted a similar mortality in California and attributes it to summer heat and desiccation. Records obtained in this study show a higher percentage of dead larvae in puparia in the 1917 counts (40 per cent of all puparia), when precipitation was below normal and the mean temperatures above normal in June, July, and August, than in the 1918 counts (17 per cent of all puparia), when precipitation was above normal and the mean temperature above normal in July and August. There must also be a very heavy mortality of first-stage larvae under unfavorable climatic conditions, as these small larvae are forced to migrate from the eggs on the leaves to the stems beneath the sheaths in order to have any chance for survival.

PARASITES

An important factor in natural control is insect parasitism. Periodical dissections by M. C. Lane in 1918 of 758 puparia from different fields showed a parasitization ranging from 16 to 75 per cent, with an average of 34 per cent for the year. In 1919, rearings from and dissections of 456 puparia showed variations in parasitization of from 15 per cent in wheat sown in May to 60 per cent in fall-sown wheat, with an average parasitization of 48 per cent. In that year

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more than 75 per cent of the parasitization was by species of Platygaster. In 1923, 900 puparia from various fields gave an average parasitization of 44 per cent.

The following species of hymenopterous parasites[9] have been reared in the course of this investigation: *Platygaster hiemalis* Forbes, *Platygaster herrickii* Pack., *Merisus destructor* Say, *Eupelmus allynii* French, *Pleurotropis epigonus* Walk., *Calosota metallica* Gahan, *Amblymerus* (*Eutelus*) *mayetiolae* Gahan, *Callitula bicolor* Spin., *Eupelminus saltator* Lind., *Eurytoma phoebus* Gir., *Eurytoma* sp., Eupteromalus (possibly two species), and *Tetrastichus carinatus* Forbes. One of the species of Eupteromalus has been found under circumstances indicating secondary parasitism on *Platygaster hiemalis*, and some of the others, while normally primary parasites, may be secondary at times. *Eupelminus saltator*, *Eurytoma* sp., and *Calosota metallica* are more commonly parasites of *Harmolita* sp. than of *Phytophaga destructor*, while *Eupelmus allynii*, also frequently reared from *Harmolita* sp., appears to be more commonly parasitic on *P. destructor*.

Platygaster hiemalis is probably the most important parasite. This species usually has two generations annually, the first appearing in May and parasitizing the offspring of the last individuals of the first spring emergence and those of the second spring emergence of Hessian flies, the second generation appearing in August and September and parasitizing the fall brood.[10] As this seasonal history differs radically from that found for this species in Pennsylvania (*7*), a further study of its seasonal history in the Pacific Northwest is being made. *P. herrickii* sometimes parasitizes considerable numbers of the first spring brood. It appears to be more susceptible to desiccation than either *P. hiemalis* or the host, *Phytophaga destructor*. Thus there is a platygasterine parasite working on each brood in this district, and the platygasterids, taken together, are probably more important than any other parasites.

The principal parasites of the puparial stage of the Hessian fly are *Merisus destructor* and *Eupelmus allynii*, although *Pleurotropis epigonus* and *Eupteromalus* sp. are quite abundant in some years. *Amblymerus mayetiolae* appears to be rare and distributed locally. It has so far been reared only from material from Kelso and Chehalis, in western Washington.

The seasonal history, the effects of environmental factors, and the rôle played by each species of parasite in the natural control of the Hessian fly in the Pacific Northwest are being further investigated.

CONTROL IN THE PACIFIC NORTHWEST

PLOWING STUBBLE FIELDS

The data given under seasonal history show that the stubble field is almost without exception the place where the Hessian fly passes the winter in this area. Wheat seeded early enough in the fall to become infested by the fall brood is now so rare as to be negligible in the infested districts of the Pacific Northwest.

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[9] All determined by A. B. Gahan.

[10] Specimens of both generations determined as *P. hiemalis* Forbes by A. B. Gahan and C. C. Hill.

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The authors believe that Hessian-fly damage to the wheat crop of western Oregon and Washington could be practically eliminated if all wheat-stubble fields were plowed and the stubble deeply buried in the fall, as soon as possible after harvest. These stubble fields contain (as puparia on the straw, or as puparia or maggots in the volunteer wheat that has sprung up following the first fall rains) practically all the Hessian flies that are likely to attack wheat in the following spring.

In some districts of western Oregon, because of local soil conditions, it may be impossible to plow the stubble under before the fall emergence in September. However, the offspring of the Hessian flies that have emerged from the stubble as the fall emergence are then located in the volunteer wheat in the stubble fields and can be destroyed by later plowing. It is important that all the stubble and volunteer wheat should be well covered so that it will not be raked to the surface by later harrowing. The flies on well-covered stubble and volunteer wheat are unable to work out through the covering soil in the following spring after the surface has been puddled by the winter rains.

A field of wheat near Forest Grove which showed 100 per cent of the plants and 80 per cent of the young tillers and culms infested in 1926 was plowed and harrowed late in the fall and seeded to oats and vetch. A few scattering volunteer wheat plants developed in this field. All the stubble was not completely buried, and a few partly buried straws containing Hessian-fly puparia were found on March 26, 1927. Yet when 10 volunteer wheat plants were examined on April 23, 1927, the only trace of the fly found on 50 tillers was one egg. These wheat plants were so few and scattered that they would have received a heavy deposition of eggs had many flies emerged in this field.

It has been observed that wheat stubble and volunteer wheat in young clover fields are the principal sources of the Hessian flies which injure near-by wheat in the spring. The practice, common in many sections of the Pacific Northwest, of seeding clover in wheat interferes with any general program for plowing wheat stubble under for control of the Hessian fly. It is doubtful whether, as a rule, the fly does enough damage to warrant a serious effort to induce farmers to abandon this usually economical practice. Should a locality suffer unusual Hessian-fly injury, it might be advisable, for a time at least, to abandon the practice of seeding clover in wheat until the Hessian fly has been controlled by plowing under the stubble. Eventually it may be found that some other method of planting clover, such as seeding alone or with some other crop, will insure better stands.

Where clover has been seeded in wheat and the stand is too good to plow up, little can be done to combat the Hessian fly. However, the farther a wheat field is located from the source of infestation, the less fly injury will develop. Hence it would be well for the farmer to plan to seed his wheat, especially very late fall-sown or spring-sown wheat (these plantings being more seriously injured by the Hessian fly than is early fall-sown wheat) as far away as possible from young clover fields containing wheat stubble. It has been observed that where a wheat field adjoins unplowed stubble, the infes-

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tation by the fly is much heavier on the side of the wheat field nearest the stubble than on the side farthest away from it, or even in the center of the field.

TIME OF SEEDING

Fall wheat should not be seeded, as a rule, until after the first week in October. The fall emergence of Hessian flies often continues until well into October, and hence wheat seeded in September becomes infested in the fall and carries the flies over winter in the planted field. Fortunately, however, because of soil conditions in the early fall, it is only rarely that any wheat is planted in the most heavily infested areas before October. This is an important factor in keeping down Hessian-fly injury in this area. It is to be hoped than an increased use of tractors, which make dry plowing and earlier seeding feasible, will not lead to an abandonment of this practice.

It has been reported (*1*) that the Oregon agricultural experiment station, at Corvallis, has found that wheat seeded about October 15 to 20 gives higher yields and is freer from weeds than wheat seeded earlier or later. Farmers should not be misled, by the idea of seeding wheat after the fall emergence of the Hessian fly is ended, into a practice of seeding at a much later date than that recommended by the Oregon experiment station. In fact, in most years wheat seeded about the first of October will have few or no Hessian flies in it in the fall, and seeding very much later than this gives no advantage to the farmer, as far as control of the Hessian fly is concerned. Wheat seeded in late November, December, January, and February has been observed to be as susceptible to spring fly injury as is early-sown spring wheat; and, as a rule, it does not yield as well as wheat seeded in October. A variety of wheat well adapted to the locality, seeded in a well-prepared seed bed at the right time, is seldom seriously injured by the Hessian fly.

In the Pacific Northwest early-sown spring wheat is usually more seriously injured by the Hessian fly than is fall-sown wheat. It has been observed that a quickly maturing variety of spring-sown wheat in a well-prepared seed bed is usually injured less than is a slow-growing variety seeded much earlier and often "mudded in." It would be advisable for those farmers who wish to plant spring wheat to secure seed of a variety that matures quickly, rather than to use seed of slowly maturing varieties, such as those commonly planted in the fall and winter.

IMMUNE OR RESISTANT VARIETIES OF WHEAT

It seems possible that profitable varieties of wheat immune or resistant to Hessian-fly injury may be developed. The variety known as Illini Chief, of a true winter habit of growth, was found to be practically immune in western Oregon in three seasons, during two of which home-grown seed was used. Although eggs of the Hessian fly were freely laid on this variety, the larvae failed to develop. However, this variety did not yield as well as a commonly grown variety, Rink, even though the latter variety was heavily infested by the fly. The variety known as Prohibition was lightly infested in experimental plots in 1919 and 1920 but did not yield as well as White Winter, Rink, or Foisy, all of which were infested to a much greater degree.

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SUMMARY

In the Pacific Northwest the Hessian fly is found only in the humid area west of the Cascade Mountains. It causes some loss of grain every year, and in some years the damage, especially to wheat seeded in the winter and early spring, has been quite serious. The greatest injury occurs in years that are favorable to a large and early second spring emergence of Hessian flies.

The Hessian fly appears to have normally at least three partial generations a year in the Pacific Northwest. The adults of these constitute three usually well-defined emergences, the time, extent, and abundance of which are largely dependent on weather conditions. The emergences are as follows: The first spring emergence, in March, April, and early May; the second spring emergence, in late May, June, or early July; and the fall emergence, in late August, September, and early October. Rarely there is a small supplemental emergence in July or early August, and sometimes another very sparse supplemental emergence in late October. While moisture and temperature are important factors in determining the emergence of flies from the puparia, other factors, now undetermined, are also involved. It is thought that the dry conditions east of the Cascade Mountains will prevent the establishment of the Hessian fly as a wheat pest in the great dry-land wheat belt of eastern Oregon and Washington.

In the Pacific Northwest Hessian flies pass the winter as larvae in puparia on wheat stubble ("holdovers" which failed to issue in the fall emergence); on volunteer wheat (the offspring of flies of the fall emergence); or on wheat seeded in September, a practice of rare occurrence. The principal sources of flies for the spring emergences, the ones that lead to damage of planted grain, are the stubble and volunteer wheat in fields of young clover.

Thirteen species of hymenopterous parasites have been reared from the Hessian fly in this area. Of these the most important are probably the species of Platygaster. One of these, *P. hiemalis* Forbes, appears normally to have two broods in this area. The seasonal history and status of these parasites are being further investigated.

Hessian-fly damage to the wheat crop of western Oregon and Washington would be practically eliminated if all wheat stubble were plowed under and deeply buried in the fall. The practice of seeding clover in wheat interferes with the general adoption of such a program, but it is doubtful whether Hessian-fly damage is normally of sufficient importance to warrant for that reason alone the abandonment of the present practice. Wheat seeded about the middle of October is usually least injured by the Hessian fly. September seedings become infested by the fall brood of Hessian flies, and wheat seeded in the winter and early spring is usually the most severely injured by the spring broods.

LITERATURE CITED

(1) ANONYMOUS.
1928. LATE WHEAT PLANTING AVOIDS EXCESSIVE WEEDS. Oreg. Farmer 47: 211, illus.

(2) BOWLES, S.
1869. OUR NEW WEST; RECORDS OF TRAVEL BETWEEN THE MISSISSIPPI RIVER AND THE PACIFIC OCEAN. 528 p., illus. Hartford.

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(3) CAREY, C. H.
1922. HISTORY OF OREGON. 1,016 p., illus. Chicago, Portland.

(4) CORDLEY, A. B.
1900. REPORT OF THE ENTOMOLOGIST. Oreg. Agr. Exp. Sta. Ann. Rpt. 1900: 24–27.

(5) DENISON, F. N., comp.
1928. CLIMATE OF BRITISH COLUMBIA. TABLES OF RAINFALL, SNOWFALL, SUNSHINE, TEMPERATURE, AND HUMIDITY; REPORT FOR 1927. 32 p. Victoria, B. C.

(6) GODDARD, F. B.
1869. WHERE TO EMIGRATE AND WHY, DESCRIBES THE CLIMATE, SOIL, PRODUCTIONS, MINERALS AND GENERAL RESOURCES, AMOUNT OF PUBLIC LANDS, THE QUALITY AND PRICE OF FARM LANDS IN NEARLY ALL SECTIONS OF THE UNITED STATES; AND CONTAINS A DESCRIPTION OF THE PACIFIC RAILROAD, THE HOMESTEAD AND OTHER LAWS, RATES OF WAGES THROUGHOUT THE COUNTRY, ETC., ETC. 591 p., illus. New York.

(7) HILL, C. C.
1926. PLATYGASTER HIEMALIS FORBES, A PARASITE OF THE HESSIAN FLY. Jour. Agr. Research 32: 261–275, illus.

(8) HUNTER, B., and JAYNE, S. O.
1918. PROFITABLE MANAGEMENT OF GENERAL FARMS IN THE WILLAMETTE VALLEY, OREGON. U. S. Dept. Agr. Bul. 705, 24 p., illus.

(9) KINCER, J. B.
1922. PRECIPITATION AND HUMIDITY, SECTION A. *In* Atlas of American Agriculture. Part II, Climate. 48 p., illus. U. S. Dept. Agr.

(10) LANG, H. O., ed.
1885. HISTORY OF WILLAMETTE VALLEY, BEING A DESCRIPTION OF THE VALLEY AND ITS RESOURCES, WITH AN ACCOUNT OF ITS DISCOVERY AND SETTLEMENT BY WHITE MEN, AND ITS SUBSEQUENT HISTORY; TOGETHER WITH PERSONAL REMINISCENCES OF ITS EARLY PIONEERS. 902 p., illus. Portland.

(11) MCCOLLOCH, J. W.
1923. THE HESSIAN FLY IN KANSAS. Kans. Agr. Expt. Sta. Tech Bul. 11, 96 p., illus.

(12) MCCONNELL, W. R.
1921. RATE OF MULTIPLICATION OF THE HESSIAN FLY. U. S. Dept. Agr. Bul. 1008, 8 p.

(13) MARCHAL, P.
1897. LES CÉCIDOMYIES DES CÉRÉALES ET LEURS PARASITES. Ann. Soc. Ent. France 66: 1–105, illus.

(14) MOSELEY, H. N.
1878. OREGON: ITS RESOURCES, CLIMATE, PEOPLE, AND PRODUCTIONS. 125 p., illus. London.

(15) MOTLEY, O. C.
1853. [LETTER]. U. S. Commr. Patents Rpt. 1852 (Pt. II, Agr.): 352–353. (U. S. Congress 32, 2d sess., House Exec. Doc. 65.)

(16) OSBORN, H.
1898. THE HESSIAN FLY IN THE UNITED STATES. U. S. Dept. Agr., Div. Ent. Bul. 16 (n. s.), 58 p., illus.

(17) PACKARD, C. M.
1928. THE HESSIAN FLY IN CALIFORNIA. U. S. Dept. Agr. Tech. Bul. 81, 26 p., illus.

(18) ROCKWOOD, L. P.
1926. THE HESSIAN FLY IN OREGON. Oreg. Agr. Expt. Sta. Circ. 77, 7 p., illus.

(19) SCHAFER, E. G., and GAINES, E. F.
1928. DISTRIBUTION OF WHEAT VARIETIES IN WASHINGTON. Wash. Agr. Expt. Sta. Bul. 224, 30 p., illus.

(20) TREHERNE, R. C.
1921. A FURTHER REVIEW OF APPLIED ENTOMOLOGY IN BRITISH COLUMBIA. Ent. Soc. Brit. Columbia, Proc. Econ. Ser. nos. 13 and 15: 135–146.

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(21) UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.
1916–1928. SUMMARIES OF CLIMATOLOGICAL DATA, OREGON SECTION. v. 5–15.

(22) ———
1926. SUMMARY OF THE CLIMATOLOGICAL DATA, FOR THE UNITED STATES, BY SECTIONS (TO 1922 INCL.). (Reprint of section 17, Western Oregon) U. S. Dept. Agr., Weather Bur. Bul. W, ed. 2, v. 1, 36 p., illus.

(23) ———
1926. SUMMARY OF THE CLIMATOLOGICAL DATA FOR THE UNITED STATES, BY SECTIONS (TO 1920, INCL.). (Reprint of section 18, Eastern Oregon) U. S. Dept. Agr., Weather Bur. Bul. W, ed. 2, v. 1, 22 p., illus.

(24) ———
1926. SUMMARY OF THE CLIMATOLOGICAL DATA FOR THE UNITED STATES, BY SECTIONS (TO 1914 INCL.). (Reprint of section 20, Eastern Washington) U. S. Dept. Agr., Weather Bur. Bul. W, ed. 2, v. 1, 26 p., illus.

(25) UNITED STATES DEPARTMENT OF THE INTERIOR, CENSUS OFFICE.
1883. [FINAL VOLUMES] REPORT ON THE PRODUCTIONS OF AGRICULTURE AS RETURNED AT THE TENTH CENSUS (JUNE 1, 1880) . . . 1,149 p., illus.

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TECHNICAL BULLETIN No. 362

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

BACTERIAL WILT OF CORN

By FREDERICK V. RAND, formerly *Senior Pathologist, Laboratory of Plant Pathology*,[1] and LILLIAN C. CASH, *Assistant Pathologist, Division of Horticultural Crops and Diseases, Bureau of Plant Industry*[2]

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INTRODUCTION AND HISTORY

The first article dealing definitely with bacterial wilt or Stewart's disease of corn is that by Stewart (*19*),[3] published in December, 1897, and reprinted the following year. The author stated that he had had this disease under observation for three years in New York, where considerable injury (20 to 100 per cent) had been done to sweet corn as grown in the market gardens of Long Island. Stewart then detailed the external and internal signs of the wilt disease and described his isolation and inoculation tests. Because of the extreme prevalence of corn wilt and the resultant infection of many of the control plants, his inoculations, though giving contributory evidence, were not fully conclusive. However, the invariable presence of countless numbers of yellow bacteria occluding the vascular elements of diseased plants gave strong evidence of a causal relation. He believed the evidence good that dissemination is chiefly through the seed and suggested stable manure and farm implements as other probable carriers of infective material. In addition to reporting from Long Island,

[1] Now Senior Pathologist, Office of Experiment Stations.

[2] The study herein reported was carried out under the general direction of the late Erwin F. Smith, formerly in charge of the Laboratory of Plant Pathology. The writers desire to acknowledge the cooperation of the West Virginia Agricultural Experiment Station, particularly for furnishing land at Morgantown for experimental purposes; the Maine Agricultural Experiment Station, particularly for supplying Maine-grown seed; H. W. Gerry and A. E. Hitchcock for assisting in taking many of the field notes near Washington, D. C., and James F. Brewer for preparing the illustrations.

[3] Italic numbers in parentheses refer to Literature Cited, p. 29.

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Stewart reported the disease from New Jersey and Iowa, in the latter case the evidence coming from New York-grown plants from Iowa seed. The germ itself he briefly described, but, without ready access to the literature, he did not name it.

In the early part of 1898, however, a culture was sent to Erwin F. Smith, of the United States Department of Agriculture, with the request that he work it over and name the organism. The early results of this cultural study were presented by Smith to the American Association for the Advancement of Science, in August, 1898, and published (*13*) in the annual report the following December. With some exceptions, he found the organism to possess the characters assigned to it by Stewart, and he added several others to distinguish it further. He described the organism, naming it *Pseudomonas stewarti*, gave its growth characters on various culture media, and added the further observation that he had seen the disease in two fields in the southwestern lake region of Michigan on flat land in dent corn sown late for fodder.

Halsted in 1899 reported (*3*) that among several varieties of corn grown together at the New Jersey Agricultural Experiment Station, only one, First-of-All, showed unmistakable signs of the bacterial disease caused by *Pseudomonas stewarti.*

Two years later Smith published a fuller account (*14*) of the cultural characters of the causal organism and in March, 1903, the " completed proof that *Pseudomonas stewarti* is the cause of the sweet-corn disease of Long Island " (*15*). In the summer of 1902 he had visited Long Island and obtained, first hand, pure cultures of the causal organism, with which he inoculated 500 sweet-corn seedlings, partly by way of the fluid oozing from water pores at the tips of the leaves and partly by spraying the plants with water suspensions of the bacteria. Both methods gave typical infections, more than 300 cases of the disease being obtained. This experiment, conducted in Washington, D. C., where corn wilt had not been previously found, gave the first fully conclusive proof of the pathogenicity of this organism and at the same time showed that wounds are not necessary for infection. The vascular system was shown to be the primary seat of the disease, though small cavities filled with the yellow bacteria finally appear in the parenchyma.

In 1909 Smith published (*16*) a brief account of experiments showing the dissemination of wilt through infected seed corn, and of tests of seed disinfection with mercuric chloride seeming to indicate benefit from the treatment. Attempts to isolate the organism from the surface of seed from the same lot were unsuccessful.

Smith's monographic account of corn wilt appeared in 1914 in his work, Bacteria in Relation to Plant Diseases (*17*, *v. 3*, *p. 89–147*). Here he gave the history and previous literature of the malady and recorded the large volume of information resulting from his own observation and experimentation over a long period. To this work and to Smith's textbook on bacterial diseases of plants (*18*, *p. 160–176*) the reader is referred for detailed descriptions of the parasite and its behavior in culture. Some other phases of his studies will be referred to in connection with the account of the present investigation.

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Several other papers referring to corn wilt have also appeared. Garman (*2*) called attention to the disease in Kentucky as occurring in 1916 in Golden Bantam corn and suggested the probability of dissemination through seed, since corn had not been grown in that field for at least 15 years.

McCulloch (*4*) in 1918 gave an account of studies of 14 isolations obtained from several States and in each case tested by successful inoculation and reisolation. In no case was true motility found, and all of the various flagella stains tested gave negative results. The name of the organism was accordingly changed to *Aplanobacter stewarti* (E. F. Smith) McCulloch.[4] Two distinct types of colony were also reported, one with a smooth surface, the other with a definite central depression or crater. Each strain continued true to type even after reisolation; otherwise in morphology and biology the two types appeared to be identical.

During the winter of 1919–20 Reddy (*9*) conducted inoculation tests, using water suspensions of bacteria from pure cultures injected into the stem bases of potted seedlings of dent, flint, and sweet corn (varieties not stated). The two series of 200 plants each gave 90 per cent of infection, and under the conditions of the test the organism appeared to be about equally infective to the three hosts used. As to intensity of infection, flint seemed most susceptible and dent least. There were no cases of natural infection from soil which immediately before had produced an artificially infected crop.

In 1924 Thomas (*21*) reported wilt as particularly destructive in Ohio on early varieties grown for the roasting-ear market, but less so on the midseason or late sorts grown for canning purposes. He gives field and greenhouse evidence of transmission through seed but little if any of transmission through the soil. Considerable experimental data are included relative to varietal differences in susceptibility, and the statement is made that all samples of northern-grown seed tested have been free from infection.

In 1925 St. John-Brooks, Nain, and Rhodes (*12*) reported a serological study as showing that the wilt organism does not agglutinate with serum of seven other yellow-pigmented plant pathogenes, viz, *Bacterium campestre*, *Bact. malvacearum*, *Bact. pruni*, *Bact. gummisudans*, *Bact. phaseoli*, *Bact. phaseoli* var. *sojense*, and *Bact. pelargoni*, tests in all cases being made with 1:100 dilution of high titer serum.

In 1926 Reddy, Holbert, and Erwin (*11*, *p. 779*) reported that no practical control of bacterial blight of sweet corn was obtained by treating the seed. When nearly disease-free seed was used, the field stands and yields were affected but little by seed treatments with organic mercury compounds.

In 1928 Reddy and Holbert (*10*) reported experimental data as showing wide differences in reaction to inoculations with *Aplanobacter stewarti* in a number of inbred lines of yellow dent corn maturing in the same length of time. All progenies of some inbred lines were uniformly high in resistance, other inbred lines were less resistant, and still others were uniformly susceptible. These results

[4] Synonymy: *Pseudomonas stewarti* E. F. Smith; *Bacterium stewarti* E. F. Smith; *Phytomonas stewarti* (E. F. Smith) Bergey et al.

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were believed to suggest the possibility of developing resistance to bacterial wilt in some of the popular wilt-susceptible varieties of sweet corn. No apparent correlation was found between wilt resistance and vegetative vigor or other important diseases of corn.

Preliminary reports of the present investigation (*6*, *7*, *8*), begun in 1918 and continued for seven years, have already been published. This series of studies was undertaken because of a lack of information in regard to the means of overwintering and summer dissemination of the disease, the relation of soil and weather conditions to its presence and spread, and the whole question of varietal differences in resistance and methods of control. This report summarizes the data obtained on these subjects.

GEOGRAPHIC DISTRIBUTION

The writers have seen the disease and isolated the causal organism in specimens from the District of Columbia, Georgia, Illinois, Indiana, Kentucky, Maryland, New Jersey, New York (including Long Island), Ohio, Virginia, West Virginia, South Carolina, and Tennessee, and in addition they have observed the disease in Connecticut, Missouri, Iowa, and Pennsylvania. In all cases typical signs of the disease were seen, including always the sticky yellow bacterial slime oozing from the cut ends of vascular bundles.

Definite published reports by others on geographical distribution of wilt include those by Stewart (*19*) from Long Island; Halsted (*3*) from New Jersey; Smith (*17*) from the District of Columbia, Long Island, Maryland, southern Michigan, Ohio, Virginia, and West Virginia; Garman (*2*) from Kentucky; Thomas (*21*) from Ohio; Tehon (*20*) from Illinois; Tucker (*22*) from Puerto Rico; Gardner (*1*) from Indiana; and Martin (*5*) from New Jersey.

Reports of the disease to the Division of Mycology and Disease Survey of the Bureau of Plant Industry, Department of Agriculture, by many observers, from 1910 to 1932, include records from the following States: Arkansas, California, Delaware, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Massachusetts, Michigan, Mississippi, Missouri, New Jersey, New Mexico, New York, North Dakota (rare), Ohio, Oklahoma, Pennsylvania, South Dakota (very minor), Tennessee, Texas, Virginia, West Virginia, and Wisconsin (very minor), and the Territory of Puerto Rico.

Further reports are as follows: Under date of July 17, 1918, E. H. Smith wrote as to California: "I have never found but one case of bacterial wilt of corn." In correspondence of July 17, 1918, Fred C. Werkenthin said: "Relative to the corn wilt caused by *Bacterium stewarti*, I wish to say that I have written to District Agent J. G. Hamilton of Albuquerque, N. Mex., in whose county I located this corn wilt last year."

For several years the present writers sought diligently for the disease in the Canadian border States of North Dakota, Minnesota, Wisconsin, Michigan, New York (northern portion), Vermont, New Hampshire, and Maine, but never found a single case, except a few affected Golden Bantam plants at Albany, N. Y., which marks the northernmost locality where they found this disease. The evidence at hand therefore seems to indicate that the disease is primarily

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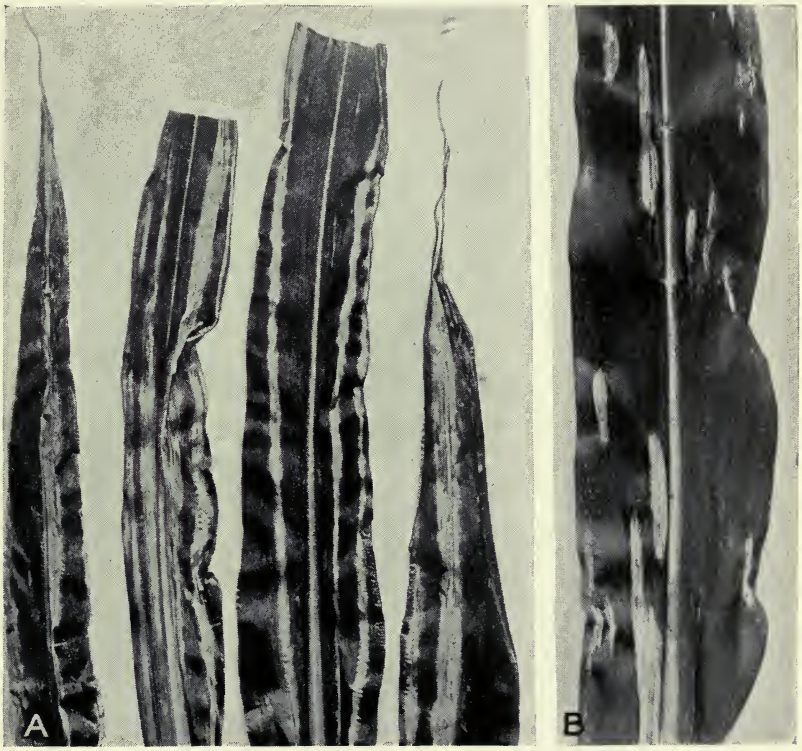

A, Typical light-green flabby streaks on corn leaves in early stages of bacterial wilt disease. B, Fungous leaf spot of corn; not to be confused with wilt disease

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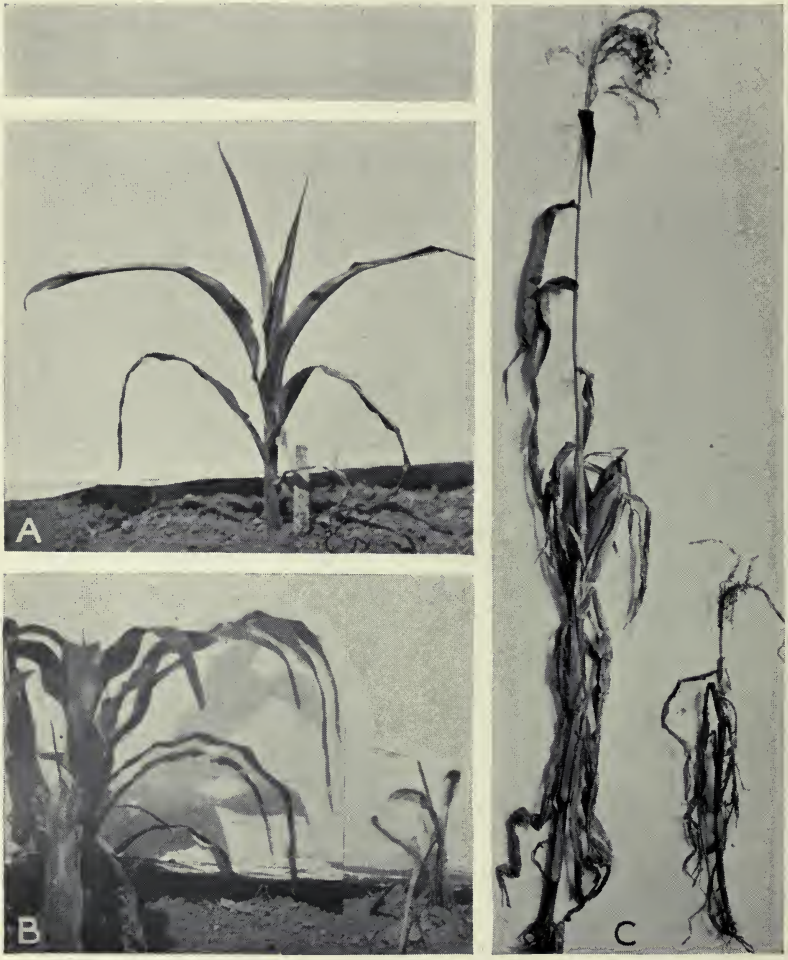

A, General diffuse type of wilt disease. B, Comparison of normal and wilt-diseased plants of the same age in adjoining hills. C, Normal and wilt-diseased corn plants from the same hill, at maturity

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A, Inner husk from wilt-diseased corn plant, showing bacterial slime oozing from the stomata. B, Corn leaves showing incipient wilt disease originating at injuries by flea beetles

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one of the Middle and Southern States and that it rarely causes appreciable damage in the northern tier of States.

SIGNS OF THE DISEASE; HOSTS; LOSSES

This specific infectious bacterial disease the writers have found under natural field conditions affecting varieties of the sweet, pop, and field corn types. It is, however, in the earlier sorts of sweet and flint corn that the inroads have been greatest, frequently amounting to the loss of practically the entire crop in seasons when, and in areas where, the disease is prevalent.

Usually the first signs to appear are long, wilted streaks of a lighter green than the adjoining healthy parts of the leaf blade, but without conspicuous yellowing. (Pl. 1, A.) On the other hand, if the progress of the disease is rapid, and especially if accompanied by dry weather, one or more leaves may turn lighter green and wilt as a whole. This diffuse type of wilting must not, however, be confused with the wilting of a tuft of the innermost leaves such as often results from insect attack at the heart of the bud; and, again, the wilted streaks should be distinguished from certain rather elongated fungous leaf spots (pl. 1, B) which frequently are first seen as spindle-shaped areas with a water-soaked appearance at the center. In bacterial wilt the external signs progress from the point of entry of the parasite, which is ordinarily the lower part of the plant when infection is from the seed or near the base of the stalk during the early stages of growth. The disease then spreads until the whole plant becomes wilted, withered, and finally dead. (Pl. 2.) Even in the dead plant some traces of the green leaf color usually remain; conspicuous yellowing never results. In some cases the tassels develop prematurely and become withered and dead before the plant as a whole has succumbed.

The most critical determining sign, however, consists in the oozing to the surface from freshly cut vascular elements of conspicuous yellowish beads of sticky bacterial slime. These bacterial masses not only occur in stems but often may be seen easily even at the cut ends of leaf veins. This slime has not been observed to ooze to the uncut surface of the plant except through the stomata in the epidermis of the inner husks of badly diseased plants. (Pl. 3, A.) In such advanced cases the vascular elements of stem and leaf are packed full of these yellow bacterial masses, which are often found also in the tissues toward the base of the kernel.

Corn wilt is primarily a disease of the vascular system, but in its later stages the parenchyma tissues are also invaded. In fact, the bacteria have been found in most parts of the plant, including roots and stems, leaf blades and sheaths, tassels, husks, cobs, and kernels.

TRANSMISSION THROUGH SEED

Many years ago the transmission of bacterial wilt of corn through the seed was shown by Smith (*17, p. 114–129*) to occur, on the basis both of strong circumstantial evidence from plantings of seed of suspected or known derivation from wilt-diseased plants, and of microscopic demonstration of the bacteria from the vascular system

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of stem and cob up into the basal region of kernels from plants known to be diseased. Because of the copious oozing of the bacterial slime to both surfaces of the husks, he suspected much of the transmission through seed to be from the surface contamination of the kernels, but failed in all attempts at direct isolation of the organism from this source. He records no attempts at isolation from the interior of the kernels, but notes the probability that infection of seedlings may come from bacteria within as well as on the surface of the kernels. The present writers have also failed in repeated attempts to isolate the organism from the seed surface; but many times during the course of the investigation they have made successful isolations from the endosperm of surface-sterilized (1:1,000 mercuric chloride) kernels, and with these pure cultures they have obtained typical infection in corn seedlings, followed by reisolation of *Aplanobacter stewarti*. Some of these isolations were made from kernels on ears collected from diseased plants in the fall and held in a corncrib until early spring.

Besides the direct isolations from seed, a considerable number of plantings were made during four years, with seed collected by the writers from wilt-diseased and healthy plants, with seed from the open market, and with seed grown in Maine and Michigan localities where the disease had not been known to occur; and careful records were made of the progeny during growth and at maturity. Brief summaries of these tests follow.

In the greenhouse, where the factor of dissemination by insects did not enter, 23 progenies of seed from a badly diseased ear, sown during the following winter in pots, gave 3 wilt-infected plants (13 per cent). In a second test, 54 progenies of seed from several badly infected ears, similarly sown, yielded 1 infected plant (2 per cent). In a third greenhouse test, 2 quarts of the worst-looking seed selected from a peck of the same lot of seed used in a large commercial planting in Maryland, from which the preceding season's crop had been almost a total failure due to bacterial wilt, was sown in a large greenhouse bed. Among the progenies of the entire lot, only 2 per cent gave definite evidence of the wilt disease. Among hundreds of plants from open-market seed grown in the same greenhouse during these tests not a single case of wilt occurred except those resulting from direct inoculation by pure cultures of the causal organism.

In larger field plantings, near Washington, D. C., where the factor of dissemination by insects was not controlled, five tests with seed collected by the writers from healthy and from wilt-infected plants gave an average of 43 and 56 per cent of wilt-infected plants, respectively. In two tests, open-market seed gave an average of 3 per cent, and seed from diseased plants 6 per cent of wilt cases.

It was reasoned that if seed were an important source of field infections, the planting of seed grown in wilt-free localities or the use of seed 2 to 3 years old ought to reduce materially the number of wilt cases. Field sowings were accordingly made, also near Washington, D. C. In one test, open-market seed gave 72 per cent, seed from Maine and Michigan 83 per cent, and seed from infected plants 78 per cent of wilt cases. In three tests, open-market seed gave an average of 48 per cent, and Maine and Michigan seed 54 per cent of infected plants. In 10 further tests in which seed 1, 2, and 3

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years old was planted at the same time under similar conditions as in all these tests, the averages for wilt-infected progenies were 17, 24, and 18 per cent, respectively.

In summarizing the foregoing, together with unpublished data from detailed notes, it may be said that *Aplanobacter stewarti* has been isolated directly from the interior of seed grown on wilt-diseased plants as long as five months after the seed was harvested. No tests for longer periods have been made. The planting of seed known to be wilt-diseased in the greenhouse has given 2 to 13 per cent of wilt cases when there was no wilt in the controls; in both these instances the factor of dissemination by insects was eliminated. Progenies of open-market seed and of seed from known healthy and wilt-diseased plants grown in the field in localities where wilt was prevalent have varied widely in individual cases in amount of wilt. However, where wilt-free and wilt-diseased seed were of the same strain and under conditions where dissemination by insects was not too great a factor, differences in percentages of wilt were sometimes very considerable. Even with the insect factor at its height, averages of considerable numbers of seed lots of the same varieties have usually given a higher percentage of wilt in the progeny of wilt-diseased than of healthy plants. Again, where the insect factor was not too prominent, the numbers of early cases and of bad cases of wilt at maturity were usually greater in progenies of wilt-diseased plants.

In spite of the clear demonstration of transmission of bacterial wilt of corn through the seed, in sections where wilt was prevalent the disease occurred in startling amounts regardless of that factor, given only that susceptible varieties were planted. For example, in field plantings in Maryland, progenies of single lots of Maryland-grown seed from healthy plants have given percentages of wilt as high as the following: Golden Bantam, 71 per cent; First-of-All, 59 per cent; Premo, 40 per cent; and Peep-o'-Day and Golden Cream, each 27 per cent. Under similar conditions, Golden Bantam seed from Maine or Michigan sections where wilt was unknown have given as high as 92 and 86 per cent, respectively, and other Maine-grown varieties have given as high as 96 per cent of wilt, when planted in Maryland. In fact, Maine and Michigan seed in general, when planted in a locality where wilt was prevalent, have given more of the disease than seed of the same varieties grown in more southern localities. This is interpreted to mean that when corn is grown in sections where wilt does not occur there is no elimination of the more susceptible strains by actual killing of the plants, such as occurs where the disease is prevalent.

Furthermore, in large field plantings of seed 1, 2, and 3 years old, the average percentages of wilt did not vary widely for progenies of the three seed groups when planted contiguously at the same time. However, individual lots of seed planted at different dates during the same season or in different seasons often showed considerable variations in amount of wilt.

Field plantings in Maryland of 470 lots of seed of two representative early and two late sorts of sweet corn obtained from seedsmen in nearly all sections of the United States gave an average of 48 per cent of wilt for the early and 5 per cent for the late sorts.

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These facts substantiate the statement that transmission by seed is a serious factor, probably the only factor, in introducing bacterial wilt of corn into a new locality; and inroads from this source alone may be considerable. It is clear, however, that once the disease becomes prevalent in a locality, the planting of resistant or susceptible varieties or strains is far more important in determining the ultimate damage to the crop from wilt than is the origin of the seed from healthy or wilt-diseased plants. These facts do not in any way minimize the danger from transmission through seed, but they do serve to emphasize the greater danger, under certain conditions, from the use of susceptible varieties.

DISINFECTION OF SEED

At the beginning of the investigation, when it was believed that a considerable proportion of seed infection originated in surface smearing with bacteria from the copious exudations through the stomata of the inner husks, several series of experiments were run to test the effects of disinfectants and dry heat on sweet-corn seed sterilized for three hours in a dry oven at 150° C., cooled, and immersed in a suspension of a three to four day agar culture of *Aplanobacter stewarti* in sterile tap water, and held one to four days before the tests.

In this way it was found that treatment with copper sulphate (1:100) or with commercial formaldehyde solution (1:320) for 15 minutes, or with the latter for 3 minutes followed by 2 hours in a formaldehyde-saturated atmosphere, was effective in destroying all the bacteria adhering to the seed.

Several trials were made in which seed treated with the bacterial suspension were submitted to dry heat at 60° C. for one to three hours, both with and without being presoaked in sterile tap water. None of the seed thus treated gave any bacterial growth when placed on sterile agar. The inoculated controls gave 88 to 100 per cent of bacterial growth when placed on sterile agar.

Since under natural conditions infection through the seed seems to come largely if not wholly through bacteria carried within the seed, it appeared problematical how far externally applied disinfectants might influence infections from this source. However, it was thought possible that if seed could be heated at a temperature high enough to destroy the bacteria without seriously impeding germination, such treatment might prove a practicable method of controlling seed transmission of the disease. The thermal death point of *Aplanobacter stewarti* being around 53° C., preliminary germination tests were carried out with seed of different sweet-corn varieties heated for different periods at 60° to 120° C. As a result it was found that germination was not seriously lowered by three hours' dry heat at 60°, 70°, or sometimes even at 80°.

A large seed-disinfectant test was then carried out in the field, with the use of seed collected the preceding fall from healthy and from wilt-diseased plants grown in the same locality. The dry-heat applications were made for 3 hours at 70° C. and for 3 and 6 hours at 80°, and the seed was planted the following day. Other lots of seed were soaked for 3 minutes in a 1:320 formaldehyde solution,

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subjected to the fumes of formaldehyde for 3 hours, and planted within 2 to 3 hours afterwards. In all, 175 lots of 100 seeds each were used in this experiment.

Careful study of the detailed results showed high variations in total percentages of wilt in comparable groups, sometimes higher in the untreated, sometimes higher in the treated, sometimes lower and sometimes higher in the healthy as compared with the wilt-diseased seed controls. Germination in these field plantings was seriously lowered by both treatments at 80° C.; that of the seeds subjected to other treatments was practically identical with that of the controls.

The wide fluctuations in percentages of wilt due to extraneous infections make it impossible to draw final conclusions. No great variations in average percentages of wilt in controls as compared with treated seed were evident. However, the heat treatments consistently gave slightly less wilt, this difference being greater the larger the number of seed lots on which the averages were based. Another field test with the use of 37 lots of 100 seeds each gave essentially similar results.

Smith (*17, p. 125–127*) carried out a test in the greenhouse using (1) 1:1,000 mercuric chloride solution for 15 minutes on hand-picked good-looking seed from a sack of seed strongly suspected of harboring the wilt organism, which gave 1.2 per cent of wilt in the progeny; (2) the same solution for 10 minutes on seed similarly selected, which gave 1.8 per cent of wilt; (3) unselected, untreated seed as it came from the sack, which gave 9 per cent of wilt; and (4) selected bad seed from the same sack, untreated, which gave 9.3 per cent of wilt. These results might seem to favor the treatment, were it not that the treated seed was the selected, best-looking seed from the sack, while the untreated seed was unselected or bad seed. Reddy, Holbert, and Erwin (*11*) found no evidence of control of bacterial wilt of corn by treating seed corn with 0.25 per cent solutions of chlorophol.

In correlating the results of the studies on disinfection of seed and on transmission through the seed, it appears that in wilt-prevalent localities transmission through seed is responsible for a much smaller proportion of the field infections than was formerly supposed, while dissemination during the growth period of the plants often reaches a percentage so high as to nearly or quite mask the effects of transmission through seed, even in the early cases. Because of the small amount of transmission through the seed and the more or less sporadic distribution of the preponderant summer dissemination, the effects of using treated rather than untreated wilt-diseased seed could scarcely become evident except where the results of large numbers of tests were averaged, or under conditions eliminating most of the secondary infections.

For practical purposes, then, seed disinfection would be of little value, even though effective, except for possible use in sterilizing seed to prevent the introduction of the disease into new localities; in such cases the treatment would need to be 100 per cent effective. Because the organisms are carried within the seed, externally applied disinfectants would probably be of little value for this purpose; the experimental results, so far as they go, bear out this idea. Heat treatment at temperatures well above the thermal death point

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(53° C.) of *Aplanobacter stewarti*, reaching all parts of the seed without materially reducing germination or vigor of the plant, would seem to offer an effective method of eliminating the organism from the seed where it is deemed advisable to make the attempt. The writers' experiments offer distinct encouragement in this respect, but need further confirmation under many widely differing conditions and the adaptation of the method to a commercial scale.

TRANSMISSION THROUGH SOIL

Since there was no conclusive information in the literature concerning the possibility of transmission of bacterial wilt of corn through the soil, the problem was approached from a number of different angles, in both greenhouse and field.

Of the field tests, five (in which about 1,400 plants and at least an equal number of uninoculated controls were used) were carried out by inoculating the soil with cut pieces of heavily infected corn stems and planting the seed among them at once. The final averages for wilt cases were 41 per cent for the inoculated soil and 38 per cent for the uninoculated controls. In these as in succeeding tests, the inocula were tested simultaneously for virulence, by successful infection of other corn seedlings. The needle-puncture method was used, and soil that had not been in corn for at least two seasons. Two similar tests (involving about 1,600 plants, with adequate controls) were carried out by burying the infected material in the fall and planting the seed the following spring. The averages were 24 per cent for the inoculated and 26 per cent for the uninoculated soil. In two other tests (on 183 plants and an equal number of controls) the soil was inoculated with a heavy tap-water suspension of the bacteria, and the corn was planted at once; averages for wilt were 70 per cent for the inoculated and 62 per cent for the uninoculated soil. In one further test (on 80 plants and an adequate number of controls) the seed rather than the soil was soaked in the bacterial suspension before planting; the averages for wilt were 74 per cent for the inoculated and 64 per cent for the uninoculated seed.

Since in these experiments insects were not controlled, two field tests (on 17 plants) were made with cloth-covered cages. Either the soil or the seed was inoculated and the seed planted at once. No wilt resulted.

It was thought that a comparison of the relative numbers of slight, medium, and bad cases of wilt to healthy plants in individual hills might possibly shed some light on the mode of infection. Accordingly, 1,865 hills of sweet corn each containing 2 to 4 plants to a hill (average 3) in a field that had not been in corn for two years were used as a basis for counts at maturity of all the hill combinations of wilt-diseased and healthy plants. Since all the bad cases of wilt first appeared early in the season, most if not all of the seed infection (if any) would be included in this group. Furthermore, if more slight or medium cases occurred in hills with bad cases than with other combinations, it would tend to indicate some relation between the two. The counts showed the following to be the most frequent hill combinations, and with the same proportion of the total number of hills (about 20 per cent) represented in each:

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Healthy alone, healthy and bad wilt, and healthy and slight wilt. Hills with bad wilt alone (10 per cent of total hills), and with healthy, slight, and bad, or with slight and bad wilt (8 per cent each), are the only other significant hill combinations. Apparently there is no clear-cut tendency for late cases to follow early cases in individual hills; and, furthermore, nearly half of 310 other hills containing only 1 plant to the hill had late-appearing cases of wilt. It seems very probable, therefore, from these data that most if not all of these late cases had become infected from sources extraneous to seed or soil.

The factor of dissemination by insects was uncontrolled in most of the field tests just summarized. Accordingly, 20 more tests were run at various times in greenhouse pots and beds, on an aggregate of at least 2,500 plants subjected to inoculation of the soil or outside of the seed in the various ways outlined for the field tests, and in each case accompanied by adequate controls.

In all these inoculation experiments, under controlled conditions and with the insect factor precluded, no single case of wilt developed except in a few plants subjected to severe root pruning, followed by immediate inoculation of the soil in contact with the cut roots. In the latter cases inoculation was, of course, merely one form of direct inoculation of the plants.

In the field tests the influences of differing soil conditions and of dissemination by insects complicated the results. However, in the one test where two distinct soil types were definitely separated in the field and thus capable of correlation, the higher percentages of wilt clearly occurred in the good rather than in the poor soil type, instead of in the inoculated rather than in the control soil; and where inoculated and uninoculated soils were both good or both poor, the percentage of wilt was about the same in both. There were many variations among the different lots of seed in a test; sometimes there was more wilt in the inoculated plots, sometimes in the controls. However, the average percentages of wilt in 7 of the 10 tests were approximately the same in both inoculated and control plots.

A correlation of the results of all of these experiments, with due regard to the conditions under which they were carried out, surely gives no clear evidence of any true transmission of infection through the soil, but, on the other hand, does give much definite evidence against it. The data at hand are interpreted to mean that overwintering of *Aplanobacter stewarti* in the soil, while it may conceivably take place in rare instances, is not a contingency likely to occur or to be of practical significance.

VARIETAL DIFFERENCES IN SUSCEPTIBILITY

Fortunately, not all varieties of corn are susceptible to bacterial wilt. Extensive varietal tests during four seasons, comprising in each season several (3 to 10) acres of land, together with varietal inoculations in the greenhouse, have shown conclusively that there now exist a considerable number of varieties highly resistant to the disease.

In the writers' first experimental field planting of about 7,000 hills near Washington, D. C., only 10 cases of wilt were found throughout

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the season. The field was separated from other cornfields by woods; the soil was a very light, sandy loam; the date of planting was preceded by several weeks without rain; and there were no commercial plantings of early sweet corn in the locality.

TABLE 1.—*Table varieties of corn arranged in the order of increasing percentage of wilt from natural infection in field plantings, 1919 and 1920*

Variety	Number of tests	Percentage of wilt	
		Range	Average
Zigzag Evergreen	2	0	0
Old Colony (1919 only)	2	0- 2	1
Stoke's Double-Barreled Best (1919 only)	2	0- 4	2
Narrow-Grained Evergreen	4	0- 8	2.3
Ideal Early	6	0- 14	3
Country Gentleman	10	0- 10	3.4
Maine Style Evergreen	2	2- 5	3.5
Stowell Evergreen	14	2- 19	4
Early Evergreen	10	0- 17	4.1
Adams' Extra Early (1919 only)	14	0- 10	4.2
Black Mexican	10	0- 25	4.6
Late Mammoth	9	0- 10	4.8
Ne Plus Ultra	4	0- 15	5.3
Perry's Hybrid (1919 only)	3	4- 7	6
Improved Giant	4	0- 10	6
Bantam Evergreen	8	0- 6	6.3
White Evergreen	2	0- 9	8
Nonesuch	3	0- 18	8.1
Long Island Beauty	3	3- 2	6.7
Early Sheffield (1919 only)	2	9- 11	10
Stabler's Early	4	3- 21	10.5
Black Sugar	2	0- 25	12.3
Bear's Foot	4	4- 34	3.6
Metropolitan	3	4- 43	14.8
Hickox	6	2- 24	15
New Early Malakoff	5	5- 33	15.5
Kendall's Early Giant	14	5- 49	16.9
Early Mammoth	5	0- 55	16.9
Improved Shoe Peg	2	8- 30	19
Golden Rod	4	12- 33	19.6
White Cory	4	4- 32	22
Howling Mob	8	3- 48	22.4
Colossal	6	4- 65	23
New Champion	3	19- 32	23.3
Moore's Early Concord	3	7- 41	25.8
Early Crosby	9	5- 70	26
Moore's Concord	4	18- 43	26.6
Premo	14	15- 59	27.3
Maule's XX	6	10- 52	29.3
Early Champion	12	22- 57	30
Early Minnesota	11	0- 53	30.1
Golden Cream	9	2- 59	30.1
Mammoth White Cory	12	4.5-100	30.2
New Extra Early White Cory	4	6.5- 68	33
Golden Bantam	28	14- 79	34.1
Early Dawn	5	22- 55	35.5
Cosmopolitan	3	32- 41	36.1
Peep-o'-Day	11	19-100	37
Mayflower	7	18- 63	40.2
Extra Early Red Cory	4	23- 65	46
Early Red Cory	3	36- 56	48
Potter's Excelsior	3	33- 50	50.5
Early Cory or First-of-All	8	30-100	57.3

Results of variety plantings of May and July during the following two years, in the same locality, are shown in Table 1. A similar variety planting of the fourth season gave percentages of wilt-diseased plants as shown in Table 2. A supplementary test of two varieties each of early and of late sweet corn, with 15 or more hills to each lot of seed, gave average percentages of wilted plants as follows: Golden Bantam (143 seed lots), 49 per cent; White Cory (36 seed lots), 48 per cent; Stowell Evergreen (142 seed lots), 4.5 per

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cent; Country Gentleman (148 seed lots), 5.4 per cent. Seed of these varieties, furnished by the Division of Seed Investigations of the Bureau of Plant Industry, came from seed companies located in

TABLE 2.—*Table varieties of corn arranged in the order of increasing percentage of wilt from natural infection in field plantings, 1921*

Variety	Number of tests	Percentage of wilt	
		Range	Average
Zigzag Evergreen	1		0
Narrow-Grained Evergreen	1		0
Ideal Early	1		0
Country Gentleman	3		0
Stowell Evergreen	5		0
White Evergreen	1		0
Early Evergreen	3		0
Leadall Evergreen [1]	1		0
Improved Giant	1		0
Nonesuch	1		0
Black Sugar	1		0
Hickox	1		0
De Lue's Golden Giant [1]	1		0
New Early Malakoff	3		0
Improved Stowell Evergreen [1]	1		1
Adams' Extra Early	2	0– 1	1.5
Ne Plus Ultra	1		1.5
Moore's Concord [1]	2	0– 3	1.5
Late Mammoth	3	0– 4.6	1.53
Adams' Early [1]	1		1.8
Long Island Beauty	1		1.85
Stabler's Early	1		1.9
Golden Evergreen [1]	1		2
Bantam Evergreen	3	0– 3	2.3
Howling Mob	2	2– 3	2.5
Cosmopolitan	1		3.17
Golden Rod	1		3.7
Black Mexican	6	0– 6	3.8
Golden Cream	3	0– 9	3.86
Maule's XX	3	3– 7	5
Bear's Foot	1		5.5
Colossal	2	0–11	5.5
White Mexican [1]	1		6
Golden Sweet [1]	1		6.8
Metropolitan	3	5– 9	7.5
Mayflower	1		9
Early Minnesota	6	4–15	9.65
Early Champion	3	5–12	9.85
White Cob Cory [1]	1		10
White Cory	1		11
Golden Giant [1]	1		11
Peep-o'-Day	2	7–18	12.5
Premo	5	4–20	13
Potter's Excelsior [1]	1		14.5
Kendall's Early Giant	4	5–48	18
Early June [1]	1		22
Mammoth White Cory	5	10–33	22
New Extra Early White Cory	1		23
Early Dawn	1		23.2
Golden Bantam	7	16–39	24.7
First-of-All	4	16– 3	25.5
Nuetta [1]	1		27
Improved Early Dakota [1]	1		32.4
Early Iowa [1]	1		37.6
Extra Early Red Cory	1		39
Early Mayflower [1]	2	40–49	41
Early Crosby	3	11–83	48

[1] Not in tests of 1919 and 1920; all others in those tests.

all sections of the United States. In all these field plantings wilt was the result of natural infection, and each test (seed lot), unless otherwise stated, represented at least 24 hills of corn.

In a further test in the greenhouse, seedlings of 24 varieties of sweet corn were inoculated by needle punctures in the stem with pure cultures of *Aplanobacter stewarti*. The average percentages

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of wilted plants for the different varieties, though of course higher than for the spontaneous infections in the field plantings, showed in general the same relative differences in susceptibility, the earlier sorts giving nearly or quite 100 per cent of infection, the later sorts 0 to 30 per cent, and the midseason sorts percentages between these two extremes.

More limited data published by Smith in 1914 (*17, p. 117–118*) and by Thomas in 1924 (*21*) agree essentially with these tests by the writers as to the relative susceptibility of sweet-corn varieties to the wilt disease.

Similar tests of 14 pop varieties and of 46 field varieties of corn, carried out by the writers during three seasons in field and greenhouse, showed entirely comparable results as to varietal differences in susceptibility. Tests with pop corn were hardly extensive enough for full varietal comparisons, but the Black Beauty and Tom Thumb varieties proved notably susceptible. In the field-corn tests the dent varieties almost invariably exhibited high resistance, while many of the flint varieties were extremely susceptible.

Variations in amount of wilt for any given variety were to be expected in different plantings and of course were realized in these tests, on account of variations in temperature, rainfall, humidity, strains of seed used, dissemination by insects, soil texture, cultural practices, presence or absence of the causal organism in the seed, etc. In view of these facts, there was a surprising correlation in the different variety groups as tested from season to season. It was found as a result of these studies that an arrangement of the sweet-corn varieties according to the length of time required for maturing coincided with surprising exactitude with an arrangement according to the relative percentages of wilt cases occurring spontaneously or from inoculation in the varieties compared. The later varieties such as Zigzag Evergreen, Country Gentleman, and Stowell Evergreen consistently gave a very low percentage of the disease, while the earliest maturing sorts, such as First-of-All and other members of the Early Cory group, Early Mayflower, Golden Bantam, Early Crosby, etc., under the same conditions underwent extreme losses, even to the point of complete destruction of crops and plants. In general, wilt prevalence among midseason varieties was between these two extremes. The Evergreen group as a whole was affected but little; and it is interesting to note that Bantam Evergreen, a cross between Golden Bantam and Stowell Evergreen, appears to carry with it very little of the susceptibility of the Golden Bantam parent. Among the 46 varieties of field corn tested under field conditions, 24 at no time showed spontaneously occurring cases of wilt; a few of the dent varieties have given 5 per cent or less, but the earlier flint sorts proved most susceptible. For example, Jehu has given as high as 100 per cent of infected plants, Square Flint 40 per cent, and Longfellow and King Philip about 20 per cent each.

As to field corn, wilt usually presents no problem, since the more susceptible flint varieties are grown for the most part in northern sections where the disease is rarely in evidence.

It is unfortunate that among the earliest table varieties the only highly resistant sorts found were in the Adams' Early and Ideal Early groups, neither of which are true sweet varieties. There is,

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however, an abundance of resistant strains among the later maturing varieties. It seems clear, then, that aside from the possible development of resistant early sorts, the only insurance against serious inroads in a locality favorable to this disease appears to lie in the planting of the already existing later varieties that have proved resistant. The compartively light occurrence of wilt usually experienced in the Middle States is to be explained in part by the fact that resistant varieties such as strains of the Evergreen or Country Gentleman types have been the ones most generally planted. On the other hand, so far as this disease is concerned, the susceptible varieties may be planted along the Canadian border with a reasonable degree of assurance. The writers have been unable to find the disease there, in either garden or commercial plantings, and only rarely has it been reported by others. Large variety tests with identical lots of seed planted during the same season in Maryland and at Orono, Me., with abundance of wilt in Maryland and none at all in Maine, surely tend to confirm the writers' extended observations.

ENVIRONMENTAL RELATIONS

TEMPERATURE AND RAINFALL

In the endeavor to elucidate the relations between weather conditions and incidence and prevalence of wilt, a considerable number of experiments and records were made, as detailed below.

The first experimental plantings were in an isolated field not planted to any crop for many years. The seed used comprised 286 lots of 149 varieties of sweet, pop, and field corn, obtained either from the congressional seed distribution or directly from dealers in 15 States, and planted in approximately 7,000 hills near Washington, D. C. In this as in succeeding tests there were not less than 24 hills to a lot of seed and not less than 3 to 4 plants to a hill. Throughout the season only 10 plants with distinct external signs of bacterial wilt were found. Varieties planted by commercial growers in this vicinity had been entirely of field corn and of late-maturing varieties of sweet corn, and the experimental field was surrounded by shrubbery and woods. The soil in this planting was a very light sandy loam; and reference to Figure 1, A, will show that dry soil conditions prevailed throughout the first part of the 1918 season; in fact, there had been no rain for several weeks prior to planting, at which time the moisture content of the surface soil was very low. Furthermore, the air-temperature readings, based on weekly averages of maximum and minimum temperatures, were comparatively low for the season and locality, and high temperatures did not prevail until after mid-July.

The following season 89 lots of 68 varieties of sweet and pop corn were planted in the same locality in three fields that had not been in corn for many years. In the first planting (May 16), out of a total of 8,716 plants, 17.5 per cent became spontaneously infected. In the second planting (July 14), out of a total of 2,414 plants, 33 per cent were attacked. In the final planting (September 3), out of a total of about 2,500 plants, only 0.2 per cent (5 cases) contracted wilt. The soil used in the first test was a moderately heavy sandy loam. At the time of the first planting the temperature was

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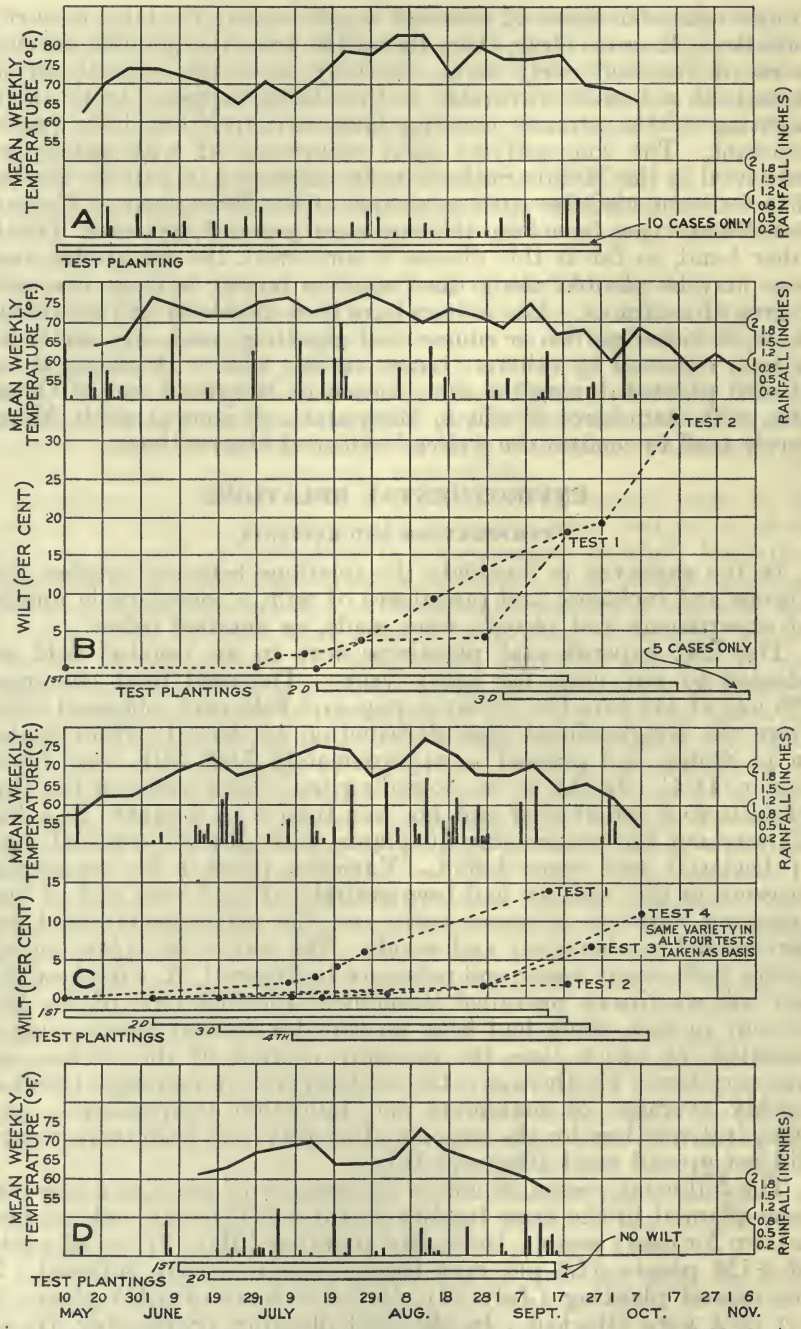

FIGURE 1.—Rainfall, temperature, and percentage of bacterial wilt in field plantings: A, Tuxedo, Md., 1918; B, Tuxedo, Md., 1919; C, Tuxedo, Md., 1920; D, Orono, Me., 1920

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rather cool (fig. 1, B), with a period of rainfall immediately preceding, and with very moist soil conditions prevailing. Here the curve of wilt incidence was very gradual at the start and became steep only during the last three weeks of the growing season.

The second planting was made during a period of heavy rainfall, in similar soil, with very moist soil conditions, and with high temperatures prevailing throughout the first two-thirds of the growing season. In this case the wilt curve was much higher and steep from the first. Furthermore, from the insect relations subsequently discovered, it seems probable that the increased infective momentum of the insect disseminators, attained during the growing period of the second planting, undoubtedly had a part in causing the more rapid rise of the second wilt curve.

The third planting was made in poorer soil, during a period of lighter rainfall and lower soil moisture, cooler nights and gradually lowering mean temperature, with consequent slower growth of the plants, and with insect prevalence lessened. The amount of wilt there was almost negligible.

During the third season the same lots of 42 varieties of sweet and pop corn were planted on May 10, June 2, June 19, and July 8, and gave, respectively, 14.3 per cent (1,541 plants), 2.1 per cent (3,859 plants), 6.5 per cent (2,359 plants), and 11.2 per cent (1,430 plants) of wilt. (Fig. 1, C.)

The first planting was made in fairly good soil with abundant soil moisture, preceded by plentiful rainfall and followed in a few days by a heavy rain, then by several weeks of drought terminated by high rainfall fairly well distributed throughout the remainder of the growing season. The temperature and wilt curves were low at first, but rose fairly rapidly later in the season.

The second planting, made in distinctly poorer soil, came in the midst of several weeks of drought. Temperatures were still rather low at first, but soon rose, and there was plentiful rainfall later on. Here the wilt curve was very low throughout.

The third planting was made in rather better soil after several days of moderate rainfall followed by heavy rains, and with decreasing, followed by rising, temperature. The wilt curve was also very low at first but later rose.

The last planting (on July 8), in fairly good soil and under favorable soil-moisture conditions, followed by unusually abundant rainfall and the highest temperatures of the season, gave a wilt curve approaching that of the first planting.

During the same season two duplicate variety tests were run at Orono, Me., comprising 139 lots of sweet and pop corn seed identical with those planted near Washington, D. C., and including also 54 lots of seed collected from wilt-infected plants the preceding season and planted June 9 and 17, respectively. Neither externally nor internally were there any signs even remotely resembling bacterial wilt in any of the plants at any time during the season. Reference to Figure 1, D (Orono, 1920), shows that there was little rainfall at or near planting time in both tests and that temperatures were comparatively low throughout the season. Furthermore, the seedlings made very slow growth during the early part of the season, seeming

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to stand still for weeks, and none of the insects later shown to be instrumental in disseminating the disease were found there.

One more large variety test near Washington, D. C., comprising 117 lots of seed of 57 varieties of sweet corn planted May 10, 1921, gave an average of 9.7 per cent of wilt cases. As shown by Figure 2, A (wilt curve not shown), abundant rainfall occurred about planting time, followed later, however, by many weeks of scant rainfall or drought. Temperatures were comparatively low during the first third of the growing season.

During several succeeding seasons date-of-planting tests were carried out at intervals throughout the growing season. In the first series, with 20 weekly plantings from April 7 to August 25, the maximum wilt prevalence occurred in the plantings of late June and early July, with less disease at the beginning and at the end of the season. There was a 6-week drought at midseason accompanying a part of this higher prevalence of wilt. However, the field notes during the growth period showed that most of the disease had come from infections contracted after the cessation of the drought. The field was a level, sandy loam soil, and all of the eight varieties used were susceptible to wilt. The disease percentages were in general low in the planting of April 7. In plantings made during the remainder of April and throughout May the wilt percentages were variable, with, however, a general tendency toward increasing wilt prevalence. The plantings of June and July were rather uniformly high in wilt prevalence, and this was the period of most uniformly high temperature of the season. The rainfall was scant in June and more plentiful in July, and the highest wilt percentages occurred in plantings made during the period of most copious rainfall and highest temperatures. In the August plantings there was a rapid falling off in wilt prevalence, reaching zero for the planting of August 25. Wilt percentages for each planting (in this and in succeeding date-of-planting tests the wilt curves are plotted on planting dates) and data on temperature and rainfall are shown in Figure 2, A.

In the second series nine plantings of the First-of-All variety were made between April 29 and July 17 in the same field. Each planting was divided into four lots, which were cut at four different dates during the last month of the growing period, the last cutting being at maturity, and therefore taken as giving the total wilt of the season. In each planting there was a general tendency toward increase in number of wilt cases at each successive cutting, even though the first cutting took place about 50 days after the date of planting of the first 5 plantings and about 40 days after planting of the last 4. This would indicate that progressive infections occurred during each growth period; and data regarding wilt cases showing yellow ooze in the vascular elements of the leaves only (incipient wilt), all of which were recent cases contracted from dissemination by insects, would show the largest percentages of infections to have taken place during midsummer, after the insect disseminators had attained their maximum infective momentum for the season. The mean weekly temperature at the first planting (fig. 2, B) was 65° F., but rapidly became higher. There had been no rain for 15 days preceding this planting, but the soil was still very moist, and five days

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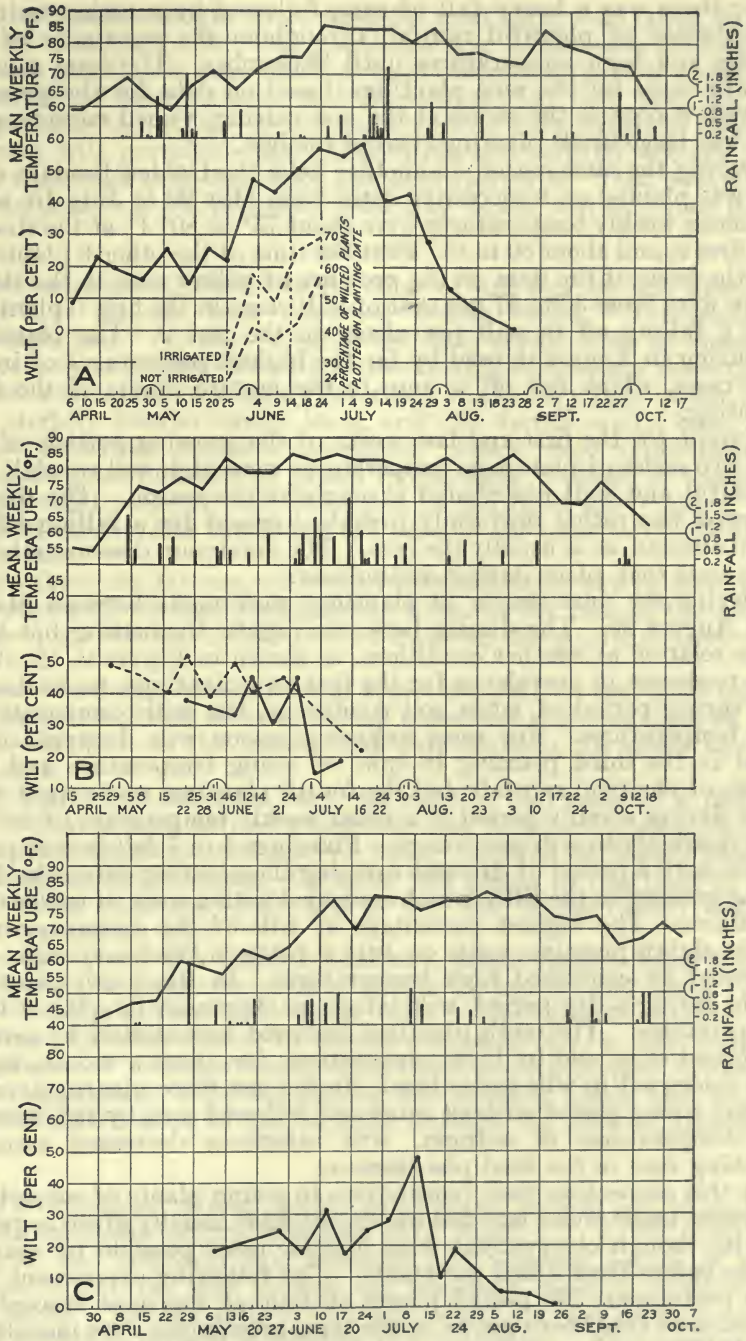

FIGURE 2.—Rainfall, temperature, and percentages of bacterial wilt in field plantings of sweet corn at Tuxedo, Md.: A, 1921; B, 1922; C, 1923. All wilt curves are plotted on planting dates and indicate the total percentage of wilt cases for each planting

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later there was a heavy fall of rain, followed by a rather uniform distribution of plentiful rainfall throughout the remainder of the season and high temperatures until September. The total number of wilt cases for the nine plantings, based on data for the presence of yellow ooze in the stems at the last cutting, varied considerably, but was large in all plantings except the last.

During the same season, in another field, the Golden Bantam variety was planted on 8 successive dates from May 22 to July 10, when the mean weekly temperatures were about 75° to 80° F. at the time of the first 2, and about 80 to 85° F. at the time of the other 6 plantings. On the basis of the data on the presence of yellow ooze in the stems, there were from 30 to 47 per cent of wilt cases in the first 6 plantings and a falling off in wilt prevalence in the last 2. The plantings maturing in August showed by far the highest percentages of incipient cases, which fell off to zero in the mature plants of the final planting.

Except for the first and last weeks of the growing periods of the last two series of plantings, temperatures were high and rainfall was plentiful and well distributed throughout the season. The disease likewise was rather uniformly prevalent except for a falling off toward autumn, as is usually the case. The maximum dissemination in both tests took place during midsummer.

During the next season 13 plantings were made between May 8 and August 25. The disease here was highly fluctuating but with some relation to weather conditions, as shown in Figure 2, C. Wilt was moderate in prevalence for the first two plantings, made during the spring period of moist soil conditions, but with comparatively low temperatures. For some unknown reason wilt dropped somewhat in the third planting in spite of rising temperature and two weeks of plentiful rainfall; but the fourth planting, made eight days later during a rainy period at a mean weekly temperature of 80° F., rose distinctly in wilt percentage. Plantings 5 to 7 fell in wilt prevalence with a period of drought covering the planting dates, the drop being greatest in the fifth, which coincided with a week of cooler temperatures. The highest percentage of wilt of the season occurred in the eighth planting, made on July 9, between two heavy rains and followed by continued high temperatures. In the ninth planting, made during a dry period, wilt infections decreased in spite of high temperatures. The tenth planting, followed immediately by several moderate rains and by high temperatures for about a month, again rose somewhat in wilt percentage. In the last three plantings, made during a long period without rains and followed soon by the decreasing temperatures of autumn, wilt infections decreased rapidly, reaching zero in the final planting.

In this connection, field inoculations in young plants of susceptible varieties, made under late-fall conditions, have usually given negative results, though observations were in some cases possible for several weeks before frost killed the plants. The following experiment was also performed: 172 potted plants of four of the most susceptible varieties of sweet corn grown in the same greenhouse were inoculated by needle punctures with pure cultures of *Aplanobacter stewarti*. The plants were then separated into two lots, each the same as to age and variety, one lot being held at 75° to 85° F., the other at 55° to

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65°. About one month later, when the final notes were taken, 83 per cent of those in the tropical greenhouse and 33 per cent of those in the cold greenhouse were found to have contracted the wilt disease.

Results of these general and date-of-planting field tests and of temperature tests in the greenhouse appear to show a definite relation between wilt prevalence and temperature and rainfall, though it is clear that other influences have also been operative. That dissemination by insects is the principal remaining factor will be shown later.

SOIL TYPE

One experiment relative to the effect of soil type on wilt development has already been discussed briefly under "Transmission Through Soil" (p. 10). During the same season rows of identical varieties were planted directly across an area comprising three types of soil which may be roughly described as (1) very light sandy soil, (2) slightly heavier sandy loam, and (3) fertile sandy loam, the whole receiving identical treatment. There were approximately the same total numbers of plants in the three portions of the plot. Thirty-eight cases of wilt developed in the light sandy third, 345 cases in the medium third, and 500 cases in the most fertile third of the plot.

In a third similar test, with about 8,000 plants on two types of soil, one poor and one fairly good sandy loam, 19 per cent of the plants on the poor soil and 28 per cent of those on the good soil were wilt infected.

In a fourth test over three soil types, the part on very poor sandy soil gave 21 per cent of wilt, that on a medium rich clay loam 41 per cent, and that on the transitional part between the other two 27 per cent.

In a fifth test the same seed was sown in two parts of a plot of newly cleared land part of which had been under cultivation during the preceding season and part of which consisted of freshly cleared soil not yet settled down. Of about 900 plants in this plot, 84 per cent in the cultivated part, and 64 per cent in the freshly cleared part contracted wilt.

In these tests the general tendency, other factors being equal, has been for a greater increase of wilt in the heavier and richer types of soil than in very light sandy soils. These results confirm the findings of earlier studies by Smith, who states (*17, p. 124*) that an abundance of moisture stimulating rapid growth is very favorable both to primary infection during the seedling stage and to the general distribution of the bacteria through the stem of the plant later on.

STUNTING

In inoculations of very thickly sown plants in pots and in similar plants subject to natural infection only, Smith (*17, p. 110, 218*) attributed the unusually low infection and retarded course of wilt disease to the very slow growth and hardened, stunted condition of the plants. The few tests of this kind which the writers have made have tended in general to confirm this conclusion. For instance, in one test with seed sown very thickly both inside and outside 18-mesh wire cages, 54 per cent of the plants inside and 80 per cent outside of the cages developed wilt from spontaneous infections.

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Plants of the same variety, three or four to a hill, but otherwise under the same conditions in contiguous rows, gave 90 per cent of wilt. Here the smaller amounts of wilt paralleled the thicker sowing, but the wire netting, which kept out a considerable number of insects, caused a much greater difference in the amount than that shown by stunted as compared with normal plants.

LOCALITY

One test as to the effect of locality has been discussed already (p. 17), in which 139 identical lots of seed planted near Washington, D. C., and at Orono, Me., gave a high percentage of wilt in Maryland and none at all in Maine.

In another test identical lots of Golden Bantam seed from Maine and from Michigan were planted near Washington, D. C., where wilt had been prevalent in experimental plots for several seasons; at Westminster, Md., where commercial plantings of Golden Bantam had been seriously damaged by wilt in preceding seasons; at Wolfville and Mountain Lake Park, Md., both mountain farming communities; at Morgantown, W. Va., on the State experiment station farm; and in two city lots in Washington, D. C. Except for a small part of the plots near Washington, D. C., all plantings were made in May and June. Wilt prevalence from spontaneous infections was highest in the May and early June plantings near Washington and at Westminster and Wolfville (northeast of Frederick), Md., and lowest in the late plantings (July and August) near Washington, followed in ascending order by plantings in the city plots, at Mountain Lake Park (extreme western border of Maryland), and at Morgantown. Records obtained near Washington, D. C., showed almost no flea beetles present July 20 to 27; they began to appear again in the fields during the first week of August, and then fell off gradually in numbers toward the close of the season. Here the decreasing wilt prevalence in general followed the decreasing prevalence of flea beetles, low rainfall, and the gradually decreasing temperatures of autumn. Both flea beetles and 12-spotted cucumber beetles were present in all the localities, but no records were kept as to relative prevalence in the other sections. Since all the seed used had been grown in Maine and Michigan localities where the disease was not known to occur, and in each case was planted in land not in corn the preceding season, it seems clear (in connection with the studies on insect relations, discussed later) that the wilt infections were due to dissemination by insects and that, the seed being the same in all localities compared, the differences in wilt prevalence were due to differences related to the insect disseminators and the concomitant climatic conditions.

During the same season plantings of Golden Bantam seed from a badly wilt-infected commercial planting of the preceding season in Maryland were made in four localities. This seed gave the highest percentages of wilted plants near Washington and at Westminster, somewhat less at Wolfville, and least at Morgantown.

Identical lots of Golden Bantam and First-of-All seed selected from plants known to be wilted were also sown in different localities. The wilt was most prevalent near Washington, followed by Wolfville, Westminster, Morgantown, and Mountain Lake Park.

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In plantings of over 60 identical lots of Golden Bantam seed sampled from the open market by the Division of Seed Investigations, Bureau of Plant Industry, wilt was found to be most prevalent near Washington, followed by Morgantown and Mountain Lake Park.

The significant results from these plantings of identical lots of seed in different localities, in all of which flea beetles were present, seem to be that (1) there was no more wilt in progeny of diseased than of healthy plants; (2) insects were responsible for most if not all of the dissemination; and (3) there was a tendency to follow flea-beetle prevalence, where known, and a secondary tendency to follow climatic conditions.

IRRIGATION

An irrigation test was carried out on a level field of very uniform sandy soil, with plantings of 30 hills each of four susceptible varieties of sweet corn to each irrigated and to each control nonirrigated plot. This test was repeated five times at different planting dates, and treated plots were irrigated uniformly twice a week, beginning at the date of planting. Averaging the results of the plots of all five planting dates, there was a little less than three-fourths as much wilt in the nonirrigated (40 per cent) as in the irrigated (55 per cent) portions. Reference to Figure 2, A, shows the general trend of wilt in these tests to be similar to that in the large general date-of-planting tests in this same field. Moderate rainfall occurred about the time of the first planting, but practically no more until some time after the last planting; this period was therefore particularly favorable for such a test.

An irrigation test carried out two years later, comprising approximately 800 plants of two susceptible varieties, gave approximately three-fourths as much wilt in the nonirrigated (23.5 per cent) as in the irrigated (31 per cent) plots.

It seems clear from these tests that soil moisture, with its concomitant more vigorous growth of plants, bears some relation, direct or indirect, to prevalence of this disease.

DISSEMINATION BY INSECTS

CIRCUMSTANTIAL EVIDENCE

After thoroughly studying the field and laboratory notes of their preliminary studies, it became very apparent to the writers that transmission through seed and soil, and climatic and soil environmental factors, were entirely inadequate to explain the observed facts relative to the origin and prevalence of wilt, but that most if not all moot points would become quite clear should insects prove to be implicated. At this stage of the investigation circumstantial evidence favoring insect dissemination was as follows:

In a general way the geographical distribution of corn wilt corresponds to that of the 12-spotted cucumber beetle, *Diabrotica duodecimpunctata* Fab., and of the flea beetles, *Chaetocnema pulicaria* Melsh. and *C. denticulata* Ill. For example, these insects are extremely common in Maryland and the District of Columbia, where wilt is particularly prevalent and destructive, and rare or absent in Maine, where the northern corn billbug and the common stalk borer are the prevailing corn insects and where wilt has been unknown.

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The 12-spotted cucumber beetle is reported to be the most injurious in wet seasons and on lowlands. The experience of the writers with bacterial wilt has been similar; and furthermore, during two dry seasons there has been a higher percentage of wilt in irrigated than in contiguous unirrigated plots otherwise similarly treated.

The sporadic appearance and spread of wilt in rows from thoroughly mixed lots of seed and in blocks planted either with the same or with different lots of seed of the same varieties suggested dissemination by insects in both primary and secondary cases.

In experimental fields in five localities in Washington, D. C., Maryland, and West Virginia, a high percentage (62 to 100 per cent) of primary bacterial wilt cases in sweet-corn seedlings showed small larval channels at the base of the stem. Plants without bacterial wilt, pulled at random in the thinning-out process in these same fields, gave a uniformly low percentage (0 to 17 per cent) of these larval channels.

Many large planting tests were made with seed from plants known to have had bacterial wilt and from plants known to have been healthy, with seed purchased in the open market, and with seed from Maine and Michigan sections where the disease was not known to occur. When these various lots of seed were planted together in a locality where wilt was prevalent the ultimate amount that developed in the progeny tended to follow the susceptibility of the variety rather than any previous history of seed or soil. In fact, under the usual field conditions in Maryland and West Virginia, seed from Maryland-grown healthy plants was as likely to give a high percentage of wilt as was that collected from badly diseased plants from the same original seed and plot. Also, the percentage of early cases appeared to be as great from wilt-free seed as from open-market or from wilt-infected seed of the same varieties.

The amount of wilt has always dwindled nearly or quite to zero in late summer plantings, even when weather conditions have been apparently as favorable as in the case of early plantings developing abundant wilt. This decrease or absence of wilt has coincided with striking decreases in the number of flea beetles and with the well-known postponement of egg laying by the last or hibernating brood of Diabrotica until spring.

In large variety tests in fresh soil, 1, 2, and 3 year old seed of the same varieties planted at the same time all gave approximately the same amount of wilt when cut at maturity. On the other hand, these same seed lots when planted at different times during the same season often gave highly variable amounts of the disease. It is extremely doubtful that approximately the same percentage of wilt could have come from seed differing so greatly in age but planted at the same time, on the one hand, or that the highly varying percentages of wilt from different times of planting could have been entirely due to differing weather conditions, on the other hand.

It was noted during several seasons' observations that a considerable proportion of cases appeared to start from the upper part of the plant; and at the end of the season cases were common in which the tip was badly wilted and gave abundant yellow ooze from the cut stem, while the basal portion of the plant showed no external or internal signs of the disease whatever. In other instances the

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middle portion was diseased, while the tip and base were normal. For example, in a field of sweet and pop corn varieties aggregating 156 rows of at least 80 hills each, there were at maturity 72 plants with distinct signs of wilt and ooze near the tip only. There were absolutely no signs of the disease, either externally or through occlusion of the vascular system (as observed under a hand lens) in the lower half of the plant, and in a large proportion of the cases external and internal signs appeared only very near the tip of the plant. Observations such as these might be multiplied. Clearly, such infections with this vascular bacterial disease could scarcely have come from either soil or seed.

In all probability, every infection arising from the seed would develop external or internal signs during the early part of the growth period. For several seasons portions of single plantings were cut, respectively, at the early tassel, late silk, premilk, and roasting-ear stages and showed a progressive increase in number of cases of the disease the longer the cutting was deferred. If all infection had come from soil or seed it is extremely improbable that a high progressive increase in number of wilt cases would have occurred at these succeeding periods of growth, since there is little doubt that practically all seed infections are evident by the tassel stage or at the latest by the silk stage.

A small block of Maine and Michigan Golden Bantam seed was planted in the middle of a large block of the wilt-resistant Stowell Evergreen variety which itself showed only traces of wilt throughout the season; the Golden Bantam seed here gave 50 per cent of wilt cases. A similar Golden Bantam block, in which the same seed lots and similar soil were used but which was planted in a field of cucurbits and near a large field of susceptible corn varieties, gave 72 per cent of wilt cases.

In a large number of cases observed in the general plantings, leaf wilt was seen to have originated at small, linear leaf injuries inflicted by flea beetles.

PRELIMINARY INSECT-EXCLUSION TESTS

In view of these various lines of circumstantial evidence, it became increasingly apparent that the facts would be explained if it could be shown that the early seasonal incidence of the disease (scattered primary cases apparently originating from the base of the plant) was due largely to introduction of the bacterial parasite by adult or larval insects working at the roots or base of the stem and that the midseason spread (secondary cases) was due to transfer of infection by insects from diseased to healthy plants. Like straws showing which way the wind blows, these facts at any rate all pointed more or less clearly to the probability of dissemination by insects.

Accordingly, a large isolated cage, 42 feet on a side, 6 feet high, and covered with 18-mesh wire netting, was used. The first season an early and a late planting of open-market seed representing a considerable number of susceptible varieties were sown in this cage, but at no time during the season did wilt appear in either planting. The disease was prevalent in plants from the same seed lots in other parts of the same locality, but there were no cornfields in the immediate vicinity of the cage.

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The following season a partition was put through the center of this cage, each side of which was then (May 23) planted to identical seed lots of susceptible varieties of sweet corn. Into one compartment considerable numbers of 12-spotted cucumber beetles previously fed upon wilt-diseased plants were introduced at frequent intervals; no insects were introduced into the other compartment. Of the approximately 250 stalks of corn developing in each of these compartments, 10 per cent developed wilt in the insect side and 12 per cent in the "insect-free" side. Some of the smaller insects could, however, gain access through the 18-mesh netting covering the cage. Therefore, in a midseason planting, with the same seed lots, no insects were introduced, but a section of the netting 2 feet wide and midway between the top and bottom of the cage was cut away from one side of one of the compartments facing a contiguous field of sweet corn where wilt was prevalent. These conditions gave free access to all insects to this compartment, but left the completely closed compartment impervious to the entrance of the larger insects and much less easily accessible to the smaller insects, but at the same time gave approximately identical conditions as to light and air movements in the two sides. At harvesting time the closed compartment gave 13 per cent of wilt cases, while the open part gave 33 per cent, which was very nearly the average for these varieties in the open field near by.

Early in the same season, in another field, each of 50 hills of the First-of-All variety was covered at planting time with 18-mesh wire-netting cages, and 36 hills were left uncovered. Early in August 40 cages were removed. Outside the cages 79 per cent of the plants developed wilt; in those covered during the first part of the season only 65 per cent and in those under the cages throughout the season 34 per cent developed wilt.

In another level field of very uniform sandy loam, comprising 54 hills of the same variety, 6 hills were covered with the wire-netting cages at each of six successive intervals of time, the first lot on the date of planting, and 18 hills were left uncovered throughout, as controls. The season's wilt record showed a progressive increase in wilt prevalence the longer the seedlings were left uncaged after planting, except for a falling off in disease percentage in two of the middle lots in which cloth cages were used.

From these preliminary tests it appeared probable that small insects were acting as disseminators and that some of them were able to pass through the fine wire netting, which, however, served as a barrier to the majority.

DIRECT TESTS WITH DIABROTICA DUODECIMPUNCTATA

During three seasons numerous direct dissemination tests were made with *Diabrotica duodecimpunctata* fed on wilt-infected plants and introduced into hill cages with susceptible varieties of sweet-corn seedlings covered from date of planting.

In the five series of tests with wire-netting cages the data were of little value so far as this insect is concerned, owing to the entrance of many small insects. However, three series of tests were run, aggregating 129 cloth-covered hill cages into which wilt-fed beetles

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were introduced and 149 such cages, used as controls, into which insects were not introduced. The full records showed, respectively, 3 and 1.2 per cent of wilt cases in the first and second insect tests (June and July) and no wilt in the third insect test (August). No wilt occurred in the 149 control cages except for five cases in cages from which the cloth covering had become torn and all clearly started from insect injuries.

Direct inoculations with intestinal contents of adults of *Diabrotica duodecimpunctata* gave a much higher proportion of infections. Three such tests were carried out in the field, with cloth-covered hill cages in which about 85 plants were inoculated with intestinal contents of wilt-fed beetles. Several of these inoculated plants developed within the first week a soft rot at the base of the stem and were therefore thrown out of the test. Out of 74 plants left, 21 per cent developed typical wilt. Three such tests, with inoculations at 1, 2, and 3 days after the wilt feeding, carried out in the greenhouse, gave very similar results.

Again, during September, 36 adult beetles, collected at random in the vicinity of several of the experimental fields where wilt was prevalent, were fed in the greenhouse upon healthy corn seedlings for three weeks. Similar inoculations were made with the intestinal contents of the 26 beetles still alive at the end of this period. Nineteen per cent of the seedlings thus inoculated finally developed wilt, with the typical ooze in the vascular bundles. A similar positive result was also obtained with the use of beetles fed for five days on seedlings with bacterial wilt from pure-culture inoculation. In this case inoculations from 16 beetles gave 25 per cent of plants with wilt and ooze. In each one of these tests one or more wilted plants taken at random were further tested by successful reinoculation into other corn seedlings.

Summing up the results of direct tests with adults of *Diabrotica duodecimpunctata*, those with wire-netting cages were inconclusive because of the entrance of other insects. However, in general, the percentage of infection was greatest in the plants outside of the cages, least in the control cages, and intermediate in plants caged with wilt-fed beetles. In the case of the cloth-covered control cages, barring accidents allowing entrance of other insects, there was no wilt in over 400 control plants. In the "insect" cages, however, there were six cases of wilt among a total of 389 plants tested with wilt-fed beetles in June and July; and no wilt among 182 plants tested during the latter three-quarters of August. Either in the direct tests or in the fields at large it was only rarely that wilt was observed to have started apparently from points gnawed by these beetles. On the other hand, many of the tests were run long enough for development of larval stages of another generation, and small channels in the base of the stem were frequently observed in the "insect" cages. These facts, taken in connection with the clear-cut results from inoculations with intestinal contents, lead to the supposition that very little of the secondary leaf infection comes from direct transfer by the mouth parts of these beetles, but that some, and possibly a considerable part, of the primary basal infection may come from their larval borings at the crown.

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DIRECT TESTS WITH FLEA BEETLES

Since flea beetles were very prevalent, and since in the general field observations numerous cases of secondary leaf infection were observed to have started apparently from the typical linear injuries made by these beetles, direct tests with these insects were planned.

As a preliminary test, 20 wilt-fed flea beetles (without regard to species determination) collected from corn were introduced at mid-season into one of the wire-netting cages covering a hill of half-grown First-of-All sweet corn. Later, wilt was directly observed starting from a considerable number of their injuries on the leaves. From some of these incipient leaf cases *Aplanobacter stewarti* was isolated in pure culture and tested by successful reinoculation in the greenhouse. There were no control cages in this test, but results seemed sufficiently clear to warrant further investigation.

During the following summer seven tests were carried out, in which was used the brassy flea beetle, *Chaetocnema pulicaria* Melsh. (determination by the Bureau of Entomology), fed 24 to 48 hours on corn plants with bacterial wilt and then introduced into cloth cages covering hills of susceptible sweet-corn varieties. In 4 of these 7 tests carried on with 16 cages having at least 4 plants to a cage, there was 100 per cent infection, and in the other 3 tests, 57, 60, and 87 per cent infection respectively. In control cages of similar type all plants remained free of wilt.

Similar experiments during a third season abundantly confirmed these results and added the toothed flea beetle, *Chaetocnema denticulata* Ill. (also determined by the Bureau of Entomology), to the list of direct disseminators. Briefly, in several field tests carried on with 16 cloth-covered cages, into each of which had been introduced 12 to 50 wilt-fed flea beetles, the records showed a total of 8 healthy plants and 40 with bacterial wilt. In other words, 83 per cent of the plants in these "insect" cages contracted the disease. The controls were the same as for the simultaneous test with *Diabrotica duodecimpunctata*, namely, out of 441 caged control plants no wilt at all appeared except in 5 plants in damaged cages which insects had entered.

Thus, the field observations and direct tests show clearly that at least in the Maryland region near Washington, D. C., where the experiments were carried out, the great bulk of the secondary infection—late spring and summer spread of the disease—is brought about by direct transfer of infectious material by flea beetles.

CONCLUSIONS

Bacterial wilt of corn, a vascular disease caused by *Aplanobacter stewarti*, occurs primarily in the Middle and Southern States; it is nonexistent or rare in the northern tier of States.

Transmission through the seed is a serious factor, probably the only factor, in introducing the disease into new localities, and inroads from this source alone may be considerable.

Because of the preponderant secondary summer dissemination of infection in a wilt-prevalent locality, the disinfection of seed under such conditions is of doubtful value. It would be of little value, even though effective, except for possible use in sterilizing seed to prevent

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the introduction of the disease into new localities, and in such cases the treatment would need to be 100 per cent effective. Since the bacterial parasite is carried within the seed, externally applied disinfectants offer little hope of such a degree of success; but dry-heat sterilization at temperatures well above the thermal death point of the bacterial organism have killed all bacteria in laboratory tests without materially reducing the rate of germination or vigor of the plants.

Experimental data show that while overwintering of *Aplanobacter stewarti* in the soil may conceivably occur, it is not likely to take place or to be of practical significance.

Wide differences in resistance to the disease were found among commercial varieties of corn. In general, the degree of resistance was roughly proportional to the length of time required for the maturing of the variety; that is, in sweet corn, the earlier the variety the more susceptible it proved; in field corn, the early flint sorts were found to be more susceptible than the dent types. Therefore, in wilt-prevalent localities, the use of well-selected resistant varieties will reduce to a minimum inroads from the disease.

Weather conditions, such as temperature, rainfall, and soil moisture, and the growth condition of the plant, have considerable influence on infection and on subsequent development of the disease, but these factors are often deeply overshadowed by the factor of dissemination by insects.

The dissemination of the wilt organism by means of the mouth parts of the adults of the 12-spotted cucumber beetle does not appear to be an important factor in the spread of the disease. This insect, however, is capable of harboring the organism in its alimentary tract over considerable periods of time.

At least for the Maryland section, flea beetles are definitely shown to be responsible for the main summer spread of bacterial wilt of corn, through secondary leaf infection by direct transfer of the wilt organism.

LITERATURE CITED

(1) GARDNER, M. W.
1928. INDIANA PLANT DISEASES, 1926. Ind. Acad. Sci. Proc. 37: 412–426, illus.

(2) GARMAN, H.
[1917]. A NEW SWEET CORN DISEASE IN KENTUCKY. Ky. Agr. Expt. Sta. Circ. 13, 4 p., illus.

(3) HALSTED, B. D.
1899. SWEET CORN SMUT AND BACTERIAL DISEASE. Bul. Torrey Bot. Club 26: 77.

(4) MCCULLOCH, L.
1918. A MORPHOLOGICAL AND CULTURAL NOTE ON THE ORGANISM CAUSING STEWART'S DISEASE OF SWEET CORN. Phytopathology 8: 440–442. illus.

(5) MARTIN, W. H.
1928. REPORT OF THE DEPARTMENT OF PLANT PATHOLOGY. N. J. Agr. Expt. Sta. Ann. Rpt. (1927/28) 49: 241–278, illus.

(6) RAND, F. V.
1923. BACTERIAL WILT OR STEWART'S DISEASE OF CORN. Canner 56(10): 164–165, illus.

(7) ——— and CASH, L. C.
1921. STEWART'S DISEASE OF CORN. Jour. Agr. Research 21: 263–264.

(8) ——— and CASH, L. C.
1924. FURTHER EVIDENCE OF INSECT DISSEMINATION OF BACTERIAL WILT OF CORN. Science (n. s.) 59: 67–69.

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(9) REDDY, C. S.
1921. EXPERIMENTS WITH STEWART'S DISEASE ON DENT, FLINT, AND SWEET CORN. (Abstract) Phytopathology 11: 31.
(10) ——— and HOLBERT, J. R.
1928. DIFFERENCE IN RESISTANCE TO BACTERIAL WILT IN INBRED STRAINS AND CROSSES OF DENT CORN. Jour. Agr. Research 36: 905–910, illus.
(11) ——— HOLBERT, J. R., and ERWIN, A. T.
1928. SEED TREATMENTS FOR SWEET-CORN DISEASES. Jour. Agr. Research 33: 769–779, illus.
(12) ST. JOHN-BROOKS, R., NAIN, K., and RHODES, M.
1925. THE INVESTIGATION OF PHYTOPATHOGENIC BACTERIA BY SEROLOGICAL AND BIOCHEMICAL METHODS. Jour. Path. and Bact. 28: 203–209.
(13) SMITH, E. F.
1898. NOTES ON STEWART'S SWEET-CORN GERM, PSEUDOMONAS STEWARTI, N. SP. Amer. Assoc. Adv. Sci. Proc. 47: 422–426.
(14) ———
1901. THE CULTURAL CHARACTERS OF PSEUDOMONAS HYACINTHI, PS. CAMPESTRIS, PS. PHASEOLI, AND PS. STEWARTI—FOUR ONE-FLAGELLATE YELLOW BACTERIA PARASITIC ON PLANTS. U. S. Dept. Agr., Div. Veg. Physiol. and Path. Bul. 28, 153 p.
(15) ———
1903. COMPLETED PROOF THAT PSEUDOMONAS STEWARTI IS THE CAUSE OF THE SWEET CORN DISEASE OF LONG ISLAND. Science (n. s.) 17: 457.
(16) ———
1909. SEED CORN AS A MEANS OF DISSEMINATING BACTERIUM STEWARTI. Science (n. s.) 30: 223–224.
(17) ———
1905–1914. BACTERIA IN RELATION TO PLANT DISEASES. 3 v., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 29.)
(18) ———
1920. AN INTRODUCTION TO BACTERIAL DISEASES OF PLANTS. 688 p., illus. Philadelphia and London.
(19) STEWART, F. C.
1897. A BACTERIAL DISEASE OF SWEET CORN. N. Y. State Agr. Expt. Sta. Bul. 130, p. 422–439, illus. Also published in N. Y. State Agr. Expt. Sta. Ann. Rpt. 16: [401]–416, illus. 1898.
(20) TEHON, L. R.
1924. A PRELIMINARY REPORT ON THE OCCURRENCE AND DISTRIBUTION OF THE COMMON BACTERIAL AND FUNGOUS DISEASES OF CROP PLANTS IN ILLINOIS. Ill. Nat. Hist. Survey Bul. 15: [173]–325, illus.
(21) THOMAS, R. C.
1924. STEWART'S DISEASE OR BACTERIAL WILT OF SUGAR CORN. Ohio Agr. Expt. Sta. Mo. Bul. 9: 81–84.
(22) TUCKER, C. M.
1927. REPORT OF THE PLANT PATHOLOGIST. Puerto Rico Agr. Expt. Sta. Rpt. 1925: 24–40, illus.

ADDENDA

(1937)

While not attempting any exhaustive survey of subsequent work (viz, since 1924) by others, the writers deem it highly advisable to refer to the following important lines of recent progress in the study of bacterial wilt of corn.

Not only has the direct summer dissemination of *Aplanobacter stewarti* by *Chaetocnema pulicaria*, *C. denticulata*, and *Diabrotica duodecimpunctata* been confirmed by Elliott and Poos (*24*), Elliott (*23*), and Poos and Elliott (*27*), but these authors have also demonstrated the overwintering of the organism in adults of *C. pulicaria*, which appear to be responsible for most of the early infections in

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the field each year. Furthermore, Ivanoff (*25*) has studied the wilt organism with special reference to its life history and pathogenesis, including the demonstration that a corn rootworm, larva of *D. longicornis*, is also able to transmit the disease from infected to healthy plants.

The natural host range of *Aplanobacter stewarti* has been extended by Elliott (*23*) to include teosinte; and successful inoculations are reported by Poos and Elliott (*27*) on teosinte and jobs-tears (*Coix* sp.), and by Ivanoff (*26*) on sorghum, Sudan grass, yellow foxtail grass, German foxtail millet, and common millet. The latter author also reports similar symptoms as induced by the organism of Cobb's disease of sugarcane on corn and sorghum in the greenhouse.

In 1934 Stevens [5] stated that—

> the outstanding disease phenomenon among cultivated plants during the past few years is undoubtedly the destruction caused by bacterial wilt of corn * * * which reached a climax in 1932 and 1933 * * *. In the years indicated above, the disease was very abundant not only within its usual range but over a large area farther north, where susceptible varieties of sweet corn had long been grown successfully. The unprecedented losses of 1932 and 1933 were followed by a sudden drop to something like normal incidence and range of the disease in 1934.

Through an exhaustive study of available records, Stevens was able to reconstruct a fairly satisfactory picture of the behavior of bacterial wilt during the preceding 35-year period in relation to winter temperatures. A careful correlation of these data impelled him to present the hypothesis that increased incidence and severity of the disease and extension of its range northward are in some way related to unusually high winter temperatures. In general, the data accumulated in subsequent years have confirmed this hypothesis.[6] Moreover, Poos and Elliott (*27, p. 607*) state that "the relationship of winter temperatures to the abundance and distribution of the insects which overwinter and disseminate *Aplanobacter stewarti* may be very significant in predicting the appearance of bacterial wilt of corn in destructive abundance"; and Haenseler,[7] while confirming Stevens' general hypothesis, states that "there seems to be a certain time factor or lag period involved which must be studied further and evaluated before a quantitative prediction of wilt incidence can be made." It appeared that after a period of severe wilt, a single cold winter is not enough to reduce the parasite or its carriers sufficiently to give the expected disease control. Likewise, after a period with but little wilt, the first warm winter may not allow a sufficient increase in the parasite or its carriers to give a serious wilt outbreak the following summer.

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[5] STEVENS, N. E. STEWART'S DISEASE IN RELATION TO WINTER TEMPERATURES. U. S. Bur. Plant Indus. Plant Disease Reptr. 18 : 141–149, illus. 1934. [Mimeographed.]

[6] STEVENS, N. E. INCIDENCE OF BACTERIAL WILT OF CORN IN THE EASTERN UNITED STATES IN 1935. U. S. Bur. Plant Indus. Plant Disease Reptr. 19 : 286–288. 1935. [Mimeographed.]

——— SECOND EXPERIMENTAL FORECAST OF THE INCIDENCE OF BACTERIAL WILT OF CORN. U. S. Bur. Plant Indus. Plant Disease Reptr. 20 : 109–113, illus. 1936. [Mimeographed.]

——— THIRD EXPERIMENTAL FORECAST OF THE INCIDENCE OF BACTERIAL WILT OF CORN. U. S. Bur. Plant Indus. Plant Disease Reptr. 21 : 102–107, illus. 1937. [Mimeographed.]

[7] HAENSELER, C. M. CORRELATION BETWEEN WINTER TEMPERATURES AND INCIDENCE OF SWEET CORN WILT IN NEW JERSEY. U. S. Bur. Plant Indus. Plant Disease Reptr. 21 : 298–301. 1937. [Mimeographed.]

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Since losses from wilt had been shown to be greatest in the early maturing commercial varieties of sweet corn, much attention has recently been paid to the selection and breeding of resistant strains and varieties. Notable in the results along these lines is the work of Smith (*28*), who presented Golden Cross Bantam, a new single cross hybrid yellow sweet corn developed in breeding investigations by the Bureau of Plant Industry in cooperation with the Indiana State Experiment Station. These studies have been continued, and seed is now available in quantity. Important progress in such work has also been made by many other experiment stations in the regions where sweet corn is commercially grown.

LITERATURE CITED (in Addenda)

(23) ELLIOTT, C.
1935. DISSEMINATION OF BACTERIAL WILT OF CORN. Iowa State Col. Jour. Sci. 9: 461–480, illus.

(24) ——— and Poos, F. W.
1934. OVERWINTERING OF APLANOBACTER STEWARTI. Science (n. s.) 80: 289–290.

(25) IVANOFF, S. S.
1933. STEWART'S WILT DISEASE OF CORN, WITH EMPHASIS ON THE LIFE HISTORY OF PHYTOMONAS STEWARTI IN RELATION TO ITS PATHOGENESIS. Jour. Agr. Research 47: 749–770, illus.

(26) ———
1935. STUDIES ON THE HOST RANGE OF PHYTOMONAS STEWARTI AND P. VASCULARUM. Phytopathology 25: 992–1002, illus.

(27) Poos, F. W., and ELLIOTT, C.
1936. CERTAIN INSECT VECTORS OF APLANOBACTER STEWARTI. Jour. Agr. Research 52: 585–608, illus.

(28) SMITH, G. M.
1933. GOLDEN CROSS BANTAM SWEET CORN. U. S. Dept. Agr. Cir. 268, 12 pp., illus.

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D.C.

THE PARASITES OF THE SUGARCANE BORER[1] IN ARGENTINA AND PERU, AND THEIR INTRODUCTION INTO THE UNITED STATES

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INTRODUCTION

Five species of Diatraea moths are reported in the United States, but only one of these, *Diatraea saccharalis* (Fab.), causes extensive injury to both sugarcane and corn. *D. crambidoides* Grote also does damage, but seems to confine itself largely to corn. It has been estimated that *D. saccharalis* alone causes an annual loss of over $3,700,000 in Louisiana.

The borer kills many young plants and considerably reduces the sugar content of the older cane. Because the larva spends practically its entire developmental period within the cane, and consequently is inaccessible, chemical control is practically impossible.

[1] *Diatraea saccharalis* (Fab.); order Lepidoptera, family Pyralidae.

[2] The courtesies and privileges accorded by the large number of owners of sugarcane estates in Peru and Argentina, and the help rendered in many ways by W. E. Cross, director, and H. E. Box, entomologist, of the Estación Experimental Agrícola de Tucumán, and other members of the station staff are gratefully acknowledged. Special thanks are due to A. H. Paton, former manager, and D. Campbell, present manager, of the Cartavio sugar estate in Peru, and to several employees who rendered help in many ways. Valuable assistance was rendered by the two temporary assistants in this work, Miguel E. Ibáñez in Argentina and Federico L. Echeandia in Peru. Acknowledgments are also made to H. C. Hallock, of the Bureau of Entomology, and W. H. Freeman, of the Bureau of Plant Quarantine, U.S. Department of Agriculture, who received and attended to the transshipment of the parasites in New York, and to J. V. Gist, of the inspection station at Miami, Fla., who arranged for the transshipment of the parasite consignments sent by airplane from Peru to New Orleans.

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Four species of parasites have been reared from Diatraea in the United States, but only one occurs in large numbers, this being the egg parasite *Trichogramma minutum* Riley. A tachinid fly, *Lixophaga diatraeae* Townsend, which is parasitic in the borer larva, was introduced from Cuba in 1918, 1919, and 1920 (*6, p. 64–65*) [3] and became established. It was found in the field for several years, but up to the present (1932) has not become an important factor in the control of the borer. It was apparent that these two parasites were not sufficient for the biological control of the borer, and that if others that would aid in reducing the injury caused by the borer could be introduced, it would be well worth the effort.

The introduction of parasites from South America for the control of the sugarcane borer, *Diatraea saccharalis*, was started in 1928.

THE FIELD OF INVESTIGATION

Wherever sugarcane is grown one or more species of moth borers that attack the cane are usually present. In each producing region various parasites live upon the sugarcane borer, *Diatraea saccharalis*. In the Province of Tucuman, Argentina, one parasitic fly and two parasitic wasps were reported as being quite effective. Inasmuch as Tucuman has a climate similar to that of New Orleans, it was thought that if these parasites could withstand the Argentine winters they might likewise withstand the climatic conditions in Louisiana.

Investigations were therefore started in August 1928, with headquarters at Tucuman. A year later, during the winter months of June and July, a trip was made to the sugarcane district along the coast of Peru. This trip revealed that two species of the parasites present in Argentina could be obtained in Peru, one of them in much larger numbers, and at a season of the year more suitable for shipment to Louisiana.

Investigations were conducted in Argentina until May 1930, and thereafter the field work was carried on in Peru with headquarters at Trujillo.

This bulletin deals only with the biology and collection of the parasites and their shipment from South America. The methods of receiving, handling, and releasing them will be dealt with by another writer.

THE PARASITES, THEIR BIOLOGY, COLLECTION, AND SHIPMENT

During the course of the studies upon the natural enemies of the sugarcane borer in South America the following 11 species of parasites were found in Argentina and Peru:

Parasites of the egg:
- Hymenoptera:
  - *Trichogramma minutum* Riley (Trichogrammatidae).
  - *Telenomus alecto* Cwfd. (Scelionidae).

Parasites of the larva:
- Diptera:
  - *Paratheresia claripalpis* Van der Wulp (Dexiidae).
  - *Leskiomima jaynesi* Aldrich (Tachinidae).

[3] Italic numbers in parentheses refer to Literature Cited, p. 25.

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Parasites of the larva—Continued.
- Hymenoptera:
  - *Ipobracon tucumanus* (Bréthes) (Braconidae).
  - *Ipobracon rimac* Wolcott (Braconidae).
  - *Bassus stigmaterus* (Cress.) (Braconidae).
  - *Apanteles xanthopus* (Ashm.) (Braconidae).
- Nematoda:
  - *Hexamermis microamphidis* Steiner (Mermithidae).
- Fungi:
  - *Botrytis delacroixii* Sacc. (Mucedineae).
  - *Mucor botryoides* Lendner (Mucoraceae).

No true pupal parasite was found, though larvae and puparia of *Paratheresia claripalpis* were sometimes found within borer pupae which had become parasitized while in the late larval stage.

PARATHERESIA CLARIPALPIS VAN DER WULP

The dexiid fly *Paratheresia claripalpis* (fig. 1), previously referred to as *Paratheresia signifera* Tns. and as *Sarcophaga diatraeae*

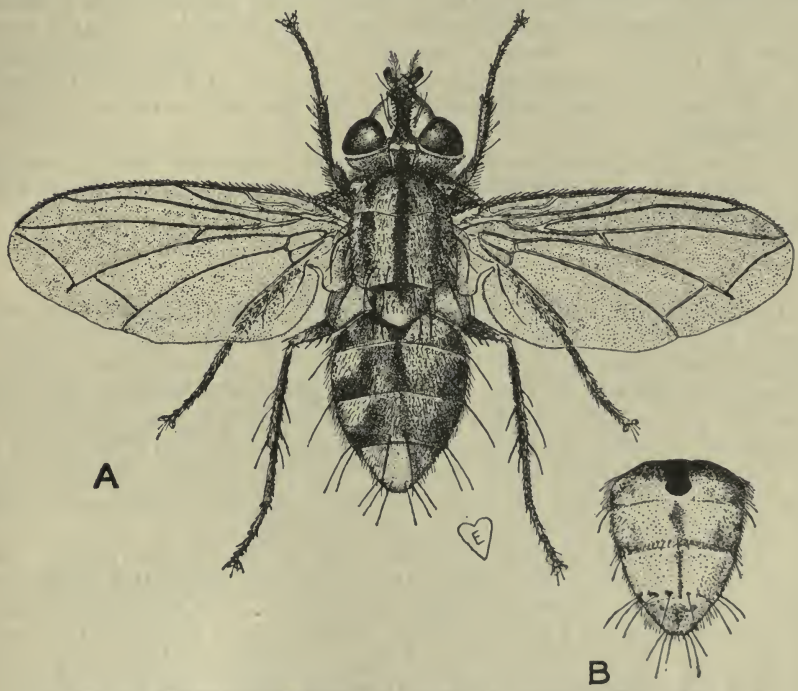

FIGURE 1.—*Paratheresia claripalpis:* A, Female; B, abdomen of the male. × 6.

Bréthes, is the most important larval parasite of the sugarcane borer in Argentina and Peru. It is also known to occur in Demerara, Trinidad, Venezuela, and Mexico. In Peru it is active throughout the year. In Argentina, though the usual hibernating stage is the first instar, within the host, those parasites that succeed in reaching the pupal stage before cold weather may emerge as adults on warm days during the winter; and therefore the fly can be found in all stages during the winter as well as the summer. Although all the borers in the cane which is taken to the mill are destroyed, a great number are left in the field in the tops and stubble, and it is in these

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borers that the parasite usually survives until the following season. There are several overlapping generations each year.

From 6 to 14 percent of the borers in mature cane in Argentina were found to be parasitized in 1928.

During the season of 1928–29 in Argentina from 2 to 22.7 percent of the borers in "dead hearts"[4] were found to be parasitized. These figures include Paratheresia puparia found at the time of examination and those which developed later from the borers. The following season the parasitization in the dead hearts was much higher, ranging from 12.9 to 68.9 percent, with an average of 34.8 percent, based on collections made on 16 different days in the two localities where the borers were most abundant. These latter percentages represent only the parasitization apparent at the time of cutting the dead hearts, as the borers that seemed healthy were used for other experiments and were not held for the emergence of additional parasites. The figures for this second season (1929–30) in Argentina compare closely with those obtained the same season in Peru, where the apparent parasitization for three fields in Cartavio averaged 32 percent. The next season, however, a total parasitization as high as 73.7 percent was noted in one field in Peru; in this case all the borers were held until the full parasite content could be determined.

The percentage of parasitization in corn was also slightly higher in Argentina in 1929–30, being 31.2 percent as compared with 29.1 percent in the preceding season.

FIELD OBSERVATIONS

During the first two years in Argentina considerable time was spent in the field trying to observe the behavior of the adults of Paratheresia, but with little success. It was not until the summer months of 1930–31 in Peru, when more flies were present, that field observations of value were obtained. Even though the infestation of the borer in both cane and corn is much greater in Peru than in Argentina, and more adult flies are actually present, yet very few were observed in the corn or cane fields—perhaps only one or two in a period of three or four hours of search.

The flies were found, however, gathered on the trunks and branches of some of the trees surrounding the fields and sometimes at a considerable distance from any field. The trees principally frequented were a kind of willow (*Salix* sp.), which is the commonest tree along the borders of the cane fields of Peru and along most of the roadways and large irrigation ditches. In some locations the flies were resting on the trunks, but again, in places that appeared identical, search for hours failed to reveal a single fly. Flies were also seen resting on soursop (*Annona muricata*), mango (*Mangifera indica*), guava (*Psidium guajava*), hog plum (*Spondias* (*lutea?*)), and orange and lemon (*Citrus* spp.), and have also been seen on the sides of buildings.

The flies are most often found on the side of the tree away from the wind, and their usual position when at rest is with the head

[4] A young sugarcane plant killed by a borer larva is called a "dead heart" because the central part of the plant, or "heart," dies first. These plants often have the outer leaves normally green, while the inner leaves are dry and dead.

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downward. They are very rapid fliers and dart back and forth, chasing one another in the bright sun, and often return to approximately the same place after a short flight. They are also active on cloudy days, although not so active as on bright, sunny days. On the tree trunks and branches the males always greatly outnumbered the females, but the greater proportion of flies collected in the cane fields were females. Upon dissection the females collected in the field proved to have been mated, though they were not always ready to larviposit, whereas those from the tree trunks had not mated or had mated only recently. It appears that, on emerging, the flies gather on tree trunks at the field borders and return to the cane fields only for food and to deposit their larvae. In Peru there are strong winds in the afternoon, at which time more flies are found on the trees.

The flies feed on juices of the cane, the secretion from mealybugs, and the honeydew of such aphids as *Sipha flava* Forbes and *Aphis maidis* Fitch, which feed mainly on cane and corn, respectively. The flies have been seen feeding on the juice of recently cut cane lying in the field.

COLLECTION AND SHIPMENT

During the first season in Argentina and Peru the puparia of *Paratheresia claripalpis* were collected by cutting out dead hearts in the cane and by splitting corn that was still green. The cane had to be cut very close to the ground in order not to injure the puparium inside, and great care was necessary to see that other shoots of cane were not cut or injured. A greater number of puparia were found in corn and were easier to obtain. In cases where the corn was being cut for fodder it was only necessary to get permission to split the stalks, but in other fields the crop had to be bought, as splitting the stalks destroyed its value. Boys were hired to collect puparia and were paid according to the number they obtained. During the second and third seasons in Peru, puparia were obtained in large numbers from the owners of small corn patches. These men were first shown samples of the puparia and the full-grown fly larvae, and arrangements were then made to buy similar specimens from them. In this way it was not necessary to buy any cornfields or supervise the cutting of the corn, and this method enabled collections to be made over a larger territory. Only those collections were bought that were in good condition and contained a fair proportion of newly formed puparia and full-grown fly larvae. If there were no larvae in the lot, it was a certain indication that the puparia had been obtained in corn that had become mature and dry, and that only a very small percentage of them would be alive.

When the puparia were received they were packed in damp sphagnum moss in small tin boxes, and a small quantity of charcoal was placed in each tin to absorb any foul gases that might be given off by decaying puparia. Several of these tin boxes were packed in a strong wooden box 9 by 12 by 7 inches, the wooden boxes being placed in ice boxes keeping a temperature of approximately 55° F. while in transit to the steamship. On board they were placed in the vegetable room of the ship at a temperature usually between 36° and 40°. The boats were met in New York, and the parasites were packed in another ice box and sent by train to New Orleans.

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The puparia were thus kept cool in storage from the time they were collected until they reached New Orleans.

A total of 637,063 puparia were forwarded from Argentina and Peru during the three seasons, as shown in table 1.

TABLE 1.—*Shipments of puparia of Paratheresia claripalpis*

Date	Country from which shipped	Puparia shipped
		Number
Jan. 24 to Apr. 18, 1929	Argentina	7,146
June 22 to July 11, 1929	Peru	27,754
June 23 to July 30, 1930	do	158,146
Apr. 23 to July 31, 1931	do	444,017
Total		637,063

An average emergence of 21.5 percent was obtained from the puparia shipped, and a total of 107,424 flies were released on 14 plantations in Louisiana (*5*).

SECONDARY PARASITIZATION

It was known that the puparia of *Paratheresia claripalpis* had been exposed to attack by secondary parasites, consequently every precaution was taken in shipment to prevent the escape of these secondaries en route and while in transit in the United States.

Secondaries were found rarely in Tucumán, and only two species were reared from the material collected there and shipped to Louisiana. The species *Aulatopria tucumana* Bréthes, reported attacking the puparia in Argentina (*3*), was not reared by the author.

In Peru, however, hyperparasitization was found to run very high, and eight species have been reared from puparia obtained in that country. The most common of these is *Thysanus dipterophaga* Gir. This is an external parasite of the fly pupa within the puparium. Several adults of this species were placed in a vial with 10 freshly formed fly puparia on July 5 and allowed to remain until July 15, when they were removed. By August 12 three healthy Paratheresia had emerged, and between September 1 and 8 six of the puparia produced a large number of the secondaries. Thus from 56 to 63 days elapsed from the time the puparia were exposed to attack until the adult secondary parasites emerged. The number of secondaries which develop in one host puparium is variable, ranging from 14 to 75, with the average between 30 and 40.

The following are the species of secondary parasites reared from the puparia of *Paratheresia claripalpis*:

Family:	
	From Argentina:
Pteromalidae	*Pachycrepoideus dubius* Ashm.
Diapriidae	*Spilomicrus* sp.
	From Peru:
Eulophidae	New genus and species.
Pteromalidae	*Melittobia* sp.
Signiphoridae	*Thysanus dipterophaga* Gir.
Signiphoridae	*Thysanus* n. sp.
Eupelmidae	*Eupelmus peruvianus* Cwfd.
Eupelmidae	*Eupelmus cushmani* Cwfd.
Spalangiidae	*Spalangia muscidarum* Rich.[5]
Diapriidae	*Trichopria* sp.

[5] Also reared in Tucumán, Argentina, from puparium of *Muscina stabulans* Fallén.

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A large number of phorid flies, reared from the material from Peru, have been identified as *Megaselia scalaria* Loew and *Megaselia* sp. The maggots of these species appeared to feed on decaying material, however, and were not parasitic on live fly puparia.

LIFE HISTORY

The fly larva, after being deposited upon the stalk of cane or corn, crawls about in search of host borers, and is guided possibly by the dark appearance of the burrow entrance and the odor of the host. When a borer has been found, the larva seeks a tender spot in a fold of the skin between the segments of the host, usually on its ventral side. It spends several minutes in searching for this point of entry and then penetrates the integument in a very short time. Inside the host it lies free in the body cavity. The duration of this first instar is variable and is considerably extended under Argentine conditions where the fly usually passes the winter months in the first larval stage within the hibernating host.

Early in the second instar the larva effects a respiratory connection with the outside air in the form of a dark chitinous funnel which envelops the posterior segments of the parasitic larva and usually appears at one of the spiracles on the eighth abdominal segment of the host. In case the borer contains two fly larvae, the respiratory funnels are usually found at two large spiracles of the eighth abdominal segment. This funnel has been found to occur also at any of the other abdominal or thoracic spiracles. In the case of artificially parasitized borers, this funnel was never evident within 24 hours, but was often found 48 hours after the parasite larva had entered the borer. When connected with its funnel, the parasite larva lies with its head directed towards that of the host. The feeding during this period is largely in the mid-abdominal and thoracic regions. This second instar covers from 77 to 144 hours, with an average of 130.6 hours, according to the laboratory observations. At the end of this feeding period a rupture is made in the skin of the borer, usually near its middle. The larva becomes detached from the funnel, molts, reverses its position, and then feeds in the posterior portion of the host's abdomen. The time spent in this position was found to be from 23 to 54 hours and to average 31 hours. The larva then leaves the empty borer skin and forms a puparium within the tunnel that the borer has made. The observed period between completion of feeding and pupation covered from 22 to 72 hours, with an average of 36.3 hours.

The time spent in the puparium averaged 21.5 days. Thus there was an average total period of 31.7 days from the time the larvae were placed on the host borers until adult flies emerged. The mean temperature during these observations was approximately 80° F.

The average time spent by the fly larvae in the various instars is as follows: First instar, free within the borer, 2 days; second instar, connected by funnel, 5.4 days; third instar, free within the borer, 1.3 days, and free outside the borer, 1.5 days; and in the puparium (as larva and pupa), 21.5 days; a total of 31.7 days.

Previous investigations in Argentina had shown that from 17 to 21 days were spent in the puparium at a mean temperature of 78.6° F., while 37 to 44 days were required at a mean temperature of 64.3°.

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Thus it is seen that with a considerably lower temperature the length of time spent in the puparium was doubled.

Fifteen fly puparia were reared from 500 borer pupae. The parasite larvae had no doubt been in the borers when the latter transformed to the pupal stage, as those borers showing parasitization sometimes pupated before the fly puparia were formed.

The newly hatched first-instar larva (fig. 2, A) is white and approximately 1 mm in length. The mouth hook is present, and the sensory papillae are very prominent. The posterior spiracles are stalked, and there are also two long setae upon the posterior segment (fig. 2, B).

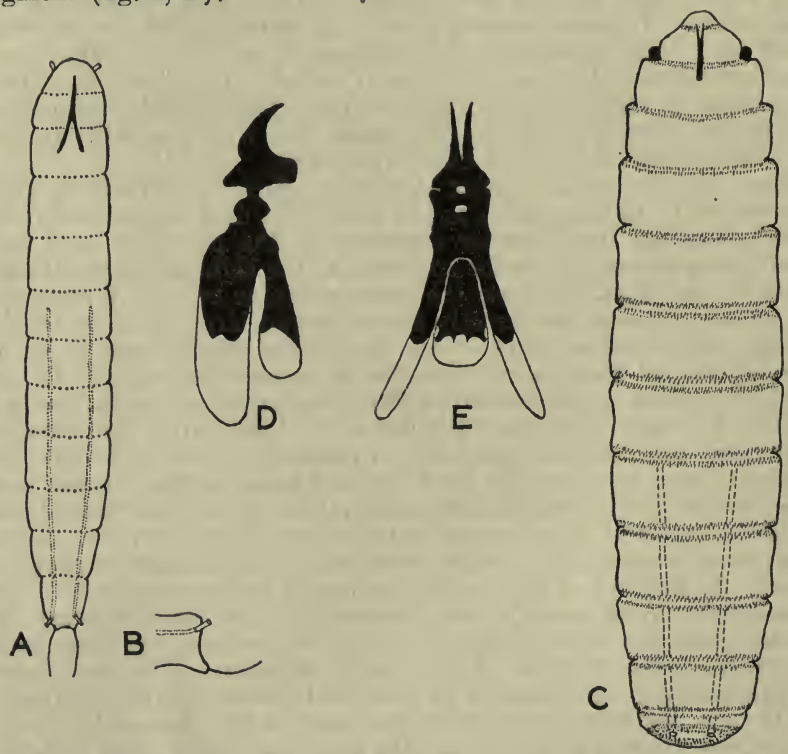

FIGURE 2.—*Parathercsia claripalpis:* A, First-instar larva, × 80; B, lateral view of caudal end of larva; C, third-instar larva, × 9; D, third-instar larval mouth parts, lateral view; E, same, dorsal view.

The second-instar larva (fig. 3, A) is 2 to 9 mm long and white. The mouth parts consist of one strong, curved hook. The posterior segments are enveloped in a chitinous tracheal funnel. This funnel appears to be attached to the spiracle of the host but actually is attached to the short spiracular trunk between the spiracle and the main tracheal trunk (fig. 3, B).

The third-instar larva (fig. 2, C) is 10 to 12 mm long and still white. The mouth parts consist of two strong, curved hooks, as illustrated in figure 2, D and E. The margins of all the segments bear numerous short, stout spines, and the last segment has several concentric rows of these spines surrounding the two spiracles.

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The puparium (fig. 4, A) is 8 to 9 mm in length, dark brown with a dull reflection, and the surface is finely striate. The posterior spiracles have three elongate depressions at the former tracheal openings.

The fly is somewhat larger than the house fly and its wings are held at a wider angle when at rest. There is a decided difference between the males and females, not only in the shape of the abdomen but also in the markings and coloration. The males are much lighter in color (fig. 1), and the females have a dark rust-colored band near the tip of the abdomen.

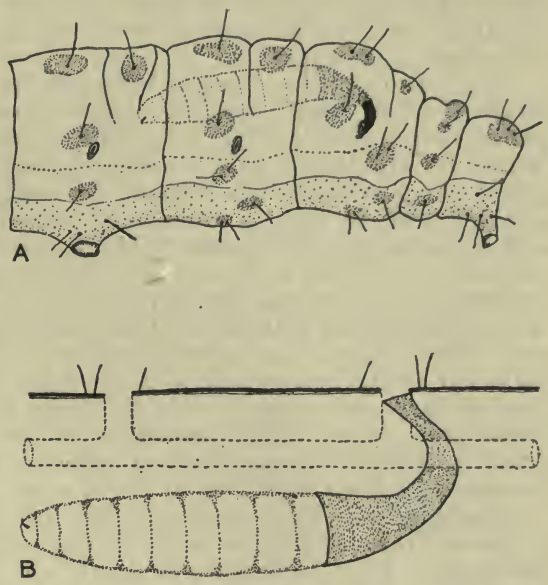

FIGURE 3.—A. *Paratheresia claripalpis*, second-instar larva showing tracheal funnel apparently attached to spiracle of host borer; B. cross section showing tracheal funnel actually attached to trachea just beneath spiracle.

The flies were found to mate within 3 or 4 days after emergence On one occasion a pair not over 40 hours old, was found mating. While mating the female is very often in the usual resting position with head directed downward, and the body of the male is at nearly a right angle to that of the female, with the tips of the wings and the hind legs resting on the tree or side of the cage. The usual period of mating was 5 or 6 minutes, but one pair was observed in union for 21 minutes.

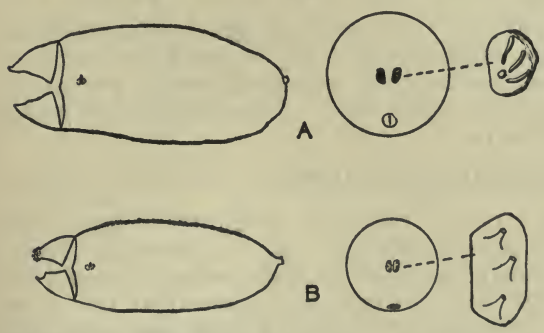

FIGURE 4.—Distinguishing characters of puparia: A, Puparium of *Paratheresia claripalpis* (× 5) and diagram of posterior spiracle (much enlarged); B, puparium of *Leskiomima jaynesi* (× 5) and diagram of posterior spiracle (much enlarged).

Several types of wire cages were tried for rearing the flies, but they all proved unsatisfactory, and mating was not obtained until cloth-covered cages were used. These cloth-covered cages were 36 inches long, 16 inches wide, and 14 inches high, and similar to those used at the gipsy moth laboratory (*4, p. 18*) for emergence and mating of tachinid flies. A sliding glass window 5 by 6 inches was placed in one end so that the flies could be observed. Granulated

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sugar, in small tin cups, was placed in the cages for food, and a sponge in a small tin was kept moist with water. The cloth was also sprinkled three or four times each day. The length of life of the fly in the field is not known, but flies in these cloth cages lived to a maximum of 41 days.

Actual larviposition has not been seen in the field, but has been observed in the cloth breeding cages. Freshly emerged flies were placed in a cage on March, 2, 3, and 4, and mating was observed on March 5. On March 13 a female was seen walking about on one of the pieces of cane. She stopped, lowered the tip of the abdomen, and appeared to expel a larva, then moved about an inch farther and repeated the movement. This was done three times. These movements were all made near one of the nodes of the cane. Upon removing the cane one fly larva was found crawling about near where the fly had been seen. It would appear that the fly expels the larvae singly. At another time a fly was observed with her abdomen at the entrance to a borer tunnel, but on examining the cane no larva was found. The fly larvae are able to penetrate the frass that is found in the aperture of the tunnel, as borers have been found successfully parasitized in infested canes where all the entrances were filled with frass at the time of larviposition.

In unfertilized females the ovaries are big, containing a large number of eggs, and the ovisac is twisted; whereas in gravid females the ovaries are considerably reduced, and the ovisac is distended with eggs and larvae (fig. 5).

The ovisacs of gravid females were found to contain 500 or more eggs and larvae. In one female which had been mated the ovisac was found to be full of eggs, a few of which had developed to the maggot stage; about a dozen of these maggots were ready for deposition. The ovisac contained 559 eggs and larvae, but the ovaries were very small and contained only a few eggs each. In another female 532 eggs, none of which had developed, were found in the ovisac.

The gestation period is from 9 to 10 days, though one female that was dissected 8 days after mating contained, in the lower portion of the distended egg sac, larvae that were sufficiently developed to penetrate borers when placed upon them. These larvae developed normally, and formed puparia.

LESKIOMIMA JAYNESI ALDRICH

Specimens of a slender yellow tachinid reared from larvae of *Diatraea saccharalis* were determined by J. M. Aldrich to be a new species, which he had recently described as *Leskiomima jaynesi* (*1*). Dr. Aldrich stated that he had received one specimen of the same species from H. E. Box, who also had reared it from the sugarcane borer, and one other specimen collected by H. H. Smith in "Piedras B.," Brazil.

In Argentina, during the season of 1928–29, only two Leskiomima flies were reared. These emerged on November 28 and December 15, 1929, in a field cage containing a large supply of cane heavily infested with Diatraea borers. This cane had been cut and placed in the cage in the latter part of September, which was very late, considering that the grinding season commences in Tucumán during June.

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In January 1929, while dead hearts were being cut open, several puparia of this species were found. These puparia appeared to be from one locality, and most of them were found in a small portion of land near Lules. All of the borers collected from this place were examined, several by dissection, but no fly larvae were found other than those which appeared to be Paratheresia.

The puparia of Leskiomima (fig. 4, B) are readily distinguishable from those of Paratheresia (fig. 4, A). They are smaller, being from 6 to 7 mm in length. At the anterior end are several short spinelike projections, there is a thoracic spiracle in the form of a

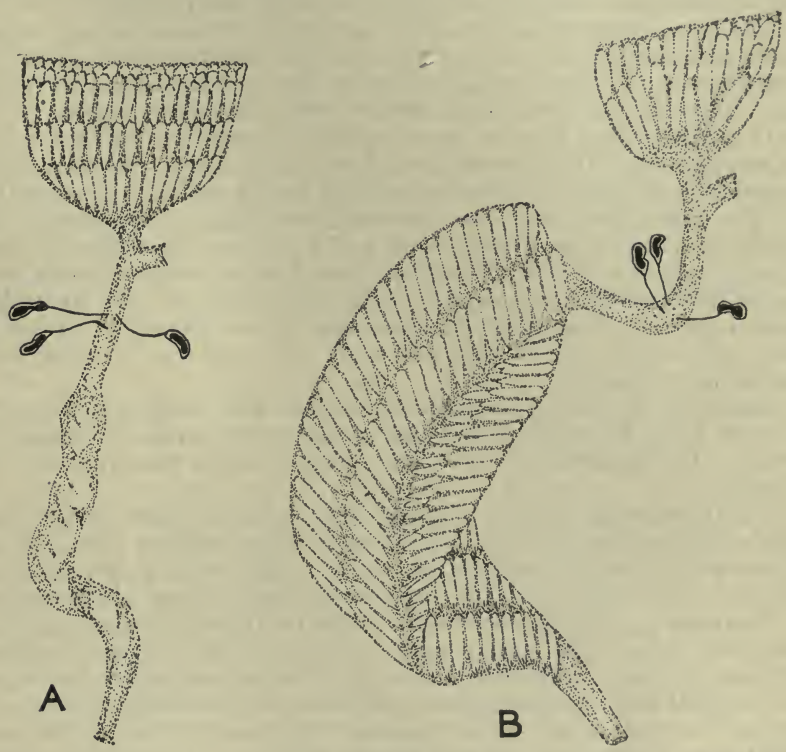

FIGURE 5.—Reproductive organs of *Paratheresia claripalpis*: A, Condition before mating, showing twisted ovisac; B, after fertilization, showing eggs and larvae in distended ovisac.

projecting tube, and each of the two posterior spiracles consists of three spinelike tubes protruding at the end.

Several reared flies were placed in a cage in February with borer-infested cane, but no parasitization resulted.

Although this fly was not found in large numbers, it may do appreciable good at times in certain small areas.

IPOBRACON TUCUMANUS BRÉTHES

GENERAL OBSERVATIONS

A large number of species of Ipobracon occur throughout Argentina, but during the investigation only a single species was definitely

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found to be parasitic upon Diatraea larvae in that country. This species has been determined by C. F. W. Muesebeck, of the Bureau of Entomology, to be *Ipobracon tucumanus*.

Ipobracon in Argentina no doubt usually passes the winter months (June, July, and August) in the adult stage. The adults can be found on warm days throughout the winter. It has been proved also that they can stand long periods of cold. Three females which emerged from a field cage were placed in a tin containing excelsior and the top was covered with muslin. This tin was placed in an ice box having a temperature between 43° and 50° F. One female lived for a month and the other two lived for over two months.

Though some 2,000 borers were removed from cane during August 1928, and continued examinations were made during September and October, the first cocoons of Ipobracon were not found until October 16. In 1929, however, a few cocoons were found in August.

It is interesting to note the number of Ipobracon cocoons found in comparison with the number of fly puparia found. In examining growing cornstalks in January 1929, at Tucumán, a record (7) of the borers and parasites obtained was kept. This showed 46 Ipobracon cocoons and 1,460 puparia and larvae of Paratheresia, or a proportion of 1 to 32. However, over 250 paralyzed borers were found at this time. A large number of these borers no doubt had been stung by Ipobracon females, and credit should be given to this species even if no parasitization was apparent, as paralyzed borers never recover.

A record of 58 collections made between February and May 1929 showed 5,762 fly puparia, 350 Ipobracon cocoons, and 47 Bassus cocoons. The Ipobracon and the fly were present in the proportion of 1 to 16.

The foregoing ratio is considerably different from that found during the previous winter. In a small lot of mature cane, cut the last week in September and placed in a field cage, there were two Ipobracon cocoons to every fly puparium when the cane was examined in November. This is explained by the fact that the cane had been standing through the winter months of June, July, August, and September, during which time the overwintering adults of Ipobracon are capable of ovipositing on warm days, whereas there is seldom a period of continuous warm weather long enough for the flies to emerge and complete the gestation period.

SHIPMENTS

A total of 421 cocoons were shipped from Tucuman between October 30, 1928, and May 13, 1929. One shipment of adults, containing 50 females and a few males collected in Guemes, was sent on May 13, 1929. In 1930, between April 16 and 19, 185 females were collected in the field near Tucuman and shipped on April 22.

BREEDING EXPERIMENTS

As it was very difficult to obtain either the adults or cocoons of Ipobracon in large numbers for shipment, efforts were made to rear them. It was hoped that these wasps could be bred under controlled conditions for two or three generations, and by such methods sufficient

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numbers could be obtained to permit shipment, either as adults or cocoons, to Louisiana.

In the middle of September 1929, Ipobracon adults were collected in the field and placed in a cage containing short pieces of artificially infested cane. The borers were placed in this cane by making a small hole with a steel punch for each one. The hole was then plugged with cotton for a short time, thus confining the borer until it had started feeding. The infested canes were then placed on end in damp sand.

The cage used was a cylinder of wire screen 10 or 12 inches in diameter and 18 inches high. A circular wire food cover of similar diameter was fastened to the top of this cylinder with brass paper fasteners, and this formed the top of the cage. To the bottom edge of the cylinder was sewed a strip of cloth 6 inches wide. This cage fitted nicely over the empty half of a kerosene tin, and the cloth was tied snugly against the tin with a string. The tins were filled with damp sand into which the infested canes were stuck. By untying the string, wasps could be added without disturbing the cage. To transfer the wasps to another tin of fresh borers it was only necessary to jar the tin to make the wasps fly to the upper part of the cage, which could then be moved with very little chance of any escaping. These cages were all used within a large outdoor cage which was supported by bricks set in a creosote solution for protection against ants and other insects.

The Ipobracon adults collected in the field readily oviposited on the borers in the cages. At the end of November most of the original adults, in addition to those that had emerged, were still alive. It was difficult to obtain hosts at this time, as the overwintering borers were just turning to pupae, and the moths were emerging. Several hundred borers had been collected and placed in canes during July, August, and September, but the mortality due to handling was exceedingly heavy, as they had to be removed from drying canes to fresh canes two or three times.

The reared adults failed to give as good results in breeding as did those collected in the field, and it was not long before their numbers began to decrease rather than increase. Mating was never observed in the cages, and very likely did not take place, and this may be the main reason for the poor results obtained from the second generation.

Two newly emerged virgin females were placed in a cage with unparasitized borers for oviposition. The progeny consisted of four males, which indicates that this species is capable of producing males parthenogenetically.

Later, experiments were tried with two large wire cages, 6½ feet square by 6½ feet high, placed over plots of uninfested corn. To infest the corn with borers two methods were used: (1) Placing two or three grown larvae on each stalk of corn; (2) placing borer eggs, which had been laid on paper in the laboratory, in the crevices where the leaf sheath joined the stalk. It was found that a much heavier infestation resulted from the eggs.

In one of these cages 13 reared females of Ipobracon were placed and in the other 26 field-collected females. Upon cutting open the corn in both of these cages only six cocoons were found. The adults flew about the top of the cage a good deal, indicating that perhaps a

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large cage is not so suitable for breeding purposes as the smaller cages. Not enough adults were obtainable, however, to give these large cages a fair trial.

LIFE HISTORY AND HABITS

The Ipobracon female inserts her ovipositor in the entrance to a tunnel, stings the borer, and then lays an egg. She is unable to select the point of stinging or to choose any definite position for the egg, owing to the variable position of the borer in the tunnel. Females which appeared to be ovipositing have been noticed at the entrances to borer tunnels, but on cutting open the cane or corn immediately after the female left, it was often found that there was no borer in the tunnel. It appears that the female must make a great many attempts for each borer actually parasitized, for the borers are often a considerable distance from the entrance hole or have already completed development and emerged.

The parasitic larva feeds externally upon the host borer at any point along its body, either ventrally or dorsally, by thrusting its mouth parts through the skin. Upon completing its feeding the larva spins a cocoon within the borer tunnel. This cocoon varies in size, depending on the size of the host upon which the larva has fed, the average being from 12 to 17 mm in length and about 4 mm in diameter. It is cylindrical, with blunt ends. The color ranges from light to dark tan, those formed in cane being darker than those in corn.

Record was kept of the period from oviposition to the emergence of the adult. Those adults which developed from eggs laid between September 19 and 28 required an average of 45.1 days, the mean temperature during this period being 69.1° F. Those which developed from eggs laid between November 12 and 16 required an average of only 25.3 days at a mean temperature of 78.5°. Thus, with the temperature approximately 10 degrees higher, only about half as much time was required in November as was required during September and October.

IPOBRACON RIMAC WOLCOTT

The only species of Ipobracon found to be parasitic upon Diatraea in Peru was *I. rimac* (fig. 6). It was very abundant in the coastal area near Trujillo, and is known to be present from Lima on the south to Chiclayo on the north. Adults can be found during all the months of the year, and at times large numbers of them, both males and females, were seen flying around corn and cane fields; at other times hundreds of males were seen flying about, but no female was visible.

SHIPMENTS

On July 9, 1929, a shipment of 150 females and 316 field-collected cocoons was made from Cartavio, Peru. The following year, between July 7 and September 9, over 20,000 females were shipped from the region around Trujillo to New York by boat and thence to New Orleans by train. In 1931, on April 23 and May 7, consignments of 4,069 and 1,794 adults, respectively, were sent by boat to New York. On May 8 the first shipment of adults by airplane was made, this

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being from Trujillo to Miami, Fla., and thence to New Orleans by train. From May 8 to September 4 a total of 32,200 adults were shipped by the air-and-rail route. These were subject to the changes in temperature encountered en route, whereas those shipped by boat were placed in the artificially cooled vegetable room of the ship.

During the first 2 years of this work the adults were shipped in tin cans 5½ inches in diameter and 9½ inches high. Several small holes were punched in the tops of the cans to allow circulation of air, and one large hole, stopped with a cork, was provided for introducing the wasps. Several small holes were also punched in the bottom to allow ventilation and to drain off any water that might collect in the can. A 5-ounce bottle containing pure water was wired to the inside of each can. A piece of gauze inserted in

FIGURE 6.—*Ipobracon rimac*, female. ×5.

the bottle served as a wick, while a plug of cotton was held in place around this wick and over the mouth of the bottle by another piece of gauze. A small tin cup, about 1 inch long, one half inch wide, and one half inch deep, was soldered to the inside of each can, and filled with granulated sugar for food. A small quantity of excelsior was placed in each container to furnish a foothold and to allow the wasps to crawl about. Later, by using a crate, without any cans, and improving the water container, the percentage received alive was increased considerably. In one crate shipped by airplane and containing 1,000 wasps, 915, or 91.5 percent, were received alive in New Orleans 7 days after being collected in Peru. From 22,168 females sent in cans, only 1,409, or 6.4 percent, were received alive, while from 15,895 sent in crates, 12,049, or 75.8 percent, were received alive. This crate was made of thin wood and measured 12

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inches long, 6 inches wide, and 9 inches high, with solid ends, bottom, and top. The two sides were covered with wire screening and black cloth, with three or four strips of wood to protect the sides from being damaged. A small tin cup containing graulated sugar was nailed to each end of the crate and also a drinking fountain containing a sponge and water. The wasps were placed in the crate through a 1-inch hole made in the top.

The drinking fountain (fig. 7) consisted of a tin can, 4 inches by 1½ inches by 1 inch, tightly sealed except for an opening three fourths inch high across one side of the bottom. At this point was soldered a cuplike arrangement 1½ by 1 by 1 inch, making the entire container L-shaped. In this lower portion a sponge was placed, which was kept moist by the water in the upright portion of the fountain. The tin was necessarily airtight, except for this opening at the bottom, so that the water would not run out. After the fountain had been filled and the sponge inserted, the fountain was inverted and nailed to the end of the crate.

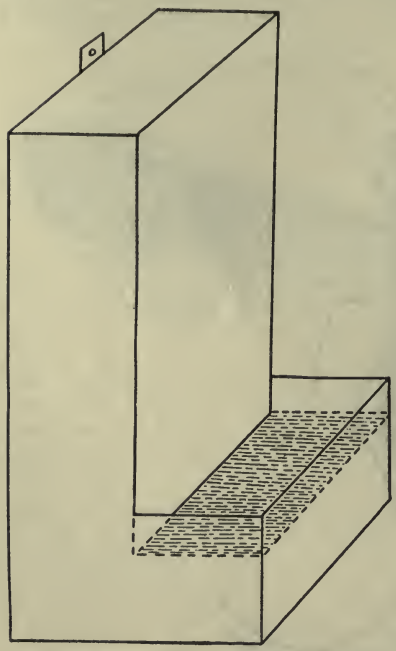

FIGURE 7.—Drinking fountain used in shipping adults of *Ipobracon rimac*.

A total of 59,632 field-collected Ipobracon females were shipped during the three seasons, and from this number 16,161 were released in Louisiana (*5*).

REARING METHODS

Females collected in the field readily oviposited upon borers in cane when placed in cages in the laboratory. The cages (fig. 8) used were 20 inches square by 2 feet high and were covered with wire netting, with the bottoms made of solid boards. Pieces of cane infested with borers were leaned against the inside of the cages. Food in the form of a sugar and water solution was sprinkled on the top of the cage at least once each day.

Of 19 females collected in the field on January 6, 1931, and placed in a cage with infested cane, 6 were still alive on February 1. During this time 42 cocoons were obtained; from these 10 females and 13 males emerged. A greater number probably would have emerged had not some of the cocoons been destroyed by ants. On February 12 an experiment was started with 5 females and 6 males, all of which had emerged recently. Canes with fresh borers were placed in the cage from time to time. The last female died on April 5, and during the intervening time 30 cocoons were obtained, which produced 18 males. No females were obtained, a fact which indicated that no mating had taken place. A similar difficulty was encountered with the Argentine species.

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LIFE HISTORY

Pieces of cane containing freshly inserted borers were placed in a cage with field-collected adults of *Ipobracon rimac*. Ovipositions were obtained, and it was found that the egg stage lasted from 24 to 48 hours.

The female stings the borer and paralyzes it so that it is unable to crawl about, though it is still able to move its legs and mouth parts slightly. Several such paralyzed borers were kept under observation. None recovered; all became black and diseased and eventually died.

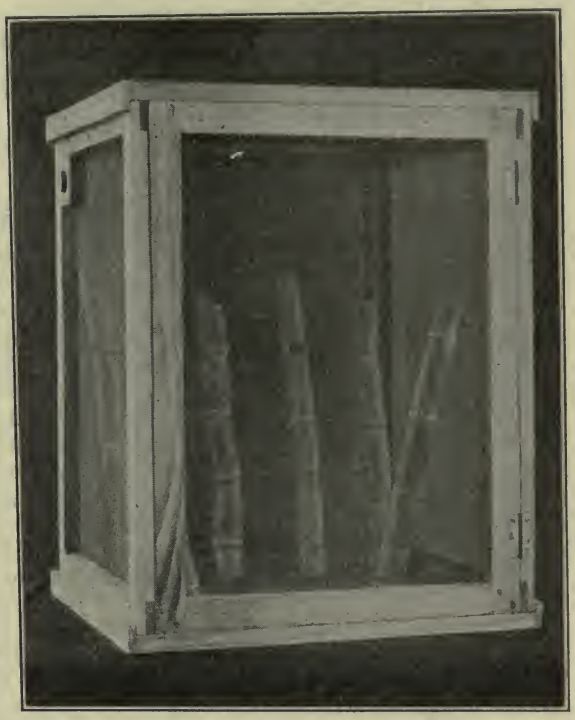

FIGURE 8.—Type of cage used for rearing *Ipobracon rimac*.

The egg is 3 mm long and 0.5 mm wide and glossy white when first laid. It is fastened by a mucilaginous substance at almost any point on the host larva. In one or two instances it was found adhering to the borer by only a small portion of the ventral face, the remainder of the egg protruding beyond the body of the borer.

Immediately after hatching the larvae move about over the body of the borer and soon start feeding, usually feeding at the same point until fully developed. It was noticed that a large proportion of the parasite larvae fed at the lateral and ventral areas of the host between the fifth and sixth segments, though the egg may have been placed between the legs or even dorsally.

On April 14 a mass of silk was found in a vial containing a borer on which an Ipobracon egg had been laid on March 31. The Ipobracon larva had unsuccessfully tried to spin a cocoon. By April 19 a white pupa was formed and on May 8 an adult male emerged. This particular individual required 38 days from deposition of the egg to the time of emergence, but earlier in the season, under the higher temperatures of January, the time required for development was usually much shorter. In these experiments the borer tunnels were not disturbed until the parasite cocoon had been formed. In January it required 8 or 9 days from the time the egg was laid until the cocoon was formed, and the cocoon period was from 11 to 14 days.

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Thus there was a total period of from 19 to 23 days from oviposition to emergence, when the mean temperature of the period was 80.2° F.

The adult females of *Ipobracon rimac* are 10 to 11 mm in length and the males are somewhat smaller. They are shining black, with the anterior three fourths of the abdomen dark red. The length of the ovipositor is slightly less than that of the body.

BASSUS STIGMATERUS (CRESS.)

The wasp *Bassus stigmaterus* was found in very small numbers in Argentina, but in Peru it was more numerous, though never very abundant. It is a delicate species, both in the adult and in the cocoon stage. During the first season in Argentina 111 cocoons of this species were shipped to the United States, and the next year only 16 cocoons, while none were sent from Peru.

A cornfield was examined on December 10, 1931, near Chiclayo, Peru, and from a few of the cornstalks the following borer and parasite material was obtained from an original borer population of 72—40 apparently healthy borers, 7 borer pupae, 8 borers showing signs of parasitization by the fly *Paratheresia claripalpis*, 13 fly puparia, 1 Ipobracon cocoon, and 3 Bassus cocoons. Later 4 additional Bassus females emerged from these borers. In this total of 72 hosts, therefore, there was 9.7 percent parasitization by Bassus. This parasitization, which was the highest found, occurred at the warmest season of the year, when this species appears to be most numerous. Among the 8 borers showing the funnel of the fly parasite *P. claripalpis* on December 10, one produced a Bassus cocoon by December 27; from this cocoon a female emerged on January 4. In this single case of apparently multiple parasitization the Bassus proved to be the stronger. However, the fly is regarded as a much more effective parasite, and instances of multiple parasitization are very rare, owing to the limited number of the wasps.

LIFE HISTORY

During November and the early part of December 1930 over 600 borers were collected from corn near Trujillo. After being carefully examined for signs of parasitization, they were inserted in pieces of cane in a cage and later examined from time to time. The live borers found on splitting the cane were reinserted in fresh cane. From these borers 6 female Bassus later emerged. One of these Bassus larvae was in the borer at least 8 days and another at least 18 days without the host showing any visible sign of parasitization. In both instances the cocoon of the parasite was formed only 6 days later. The length of time spent in the cocoon ranges from a week to 10 days.

Bassus stigmaterus makes a cocoon decidedly different from that of Ipobracon. It is thin, a transparent grayish-white, about 16 mm long and 4 mm in diameter, and tapers to pointed ends. It is extremely delicate and is difficult to handle without injuring the contents, whereas the Ipobracon cocoon is comparatively strong and not injured by handling.

The female Bassus is about 9 mm in length and dark red. The body is much more slender than that of the Ipobracon and the ovi-

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positor is longer than the body. No males of this species were reared or collected.

In Argentina this species passes the winter months in the first larval instar within the host borer. It is readily seen that the duration of this instar is the most variable and depends largely on the season of the year. The later larval instar periods and the pupal period within the cocoon are very short.

TELENOMUS (PROPHANURUS) ALECTO CWFD.

The egg parasite *Telenomus alecto* was not found in the Province of Tucuman, though collections of egg clusters were made in search of it during the seasons of 1928–29 and 1929–30. Box (*2*) has reported finding it in the Province on only one occasion. However, it was found to be present in fairly large numbers at Guemes, in the adjoining Province of Salta.

Between February 18 and 21, 1929, collections of egg clusters were made at Guemes, and 190 egg clusters were obtained in 9 hours. Only five scars were found on leaves indicating where egg clusters had been washed off, and no cluster was found that was not parasitized at least in part. The failure to find unparasitized clusters may have been due to the fact that because of their light color they were considerably harder to discern on the leaves than were the parasitized eggs, which are black. In this lot of 1,709 eggs were 943 parasitized eggs in apparently good condition, 742 parasitized eggs from which the parasite had emerged, and 24 eggs not parasitized. The parasitized eggs included those attacked either by Trichogramma or by Telenomus.

One hundred of these clusters obtained in Guemes were examined on February 26, and each cluster was placed in a small vial and held for emergence. There were 141 eggs from which parasites had emerged and 745 eggs which still contained parasites. From this material there emerged over 1,000 adults of *Trichogramma minutum* and 75 of *Telenomus alecto.*

After emergence four or five Telenomus individuals were placed in a small glass vial with cane-borer eggs which had been laid upon paper. Fresh borer eggs were supplied on alternate days. No mating was observed, but oviposition took place, and later some of the eggs turned black. Upon dissection, each dark-colored egg was found to contain one parasite. However, the writer succeeded in obtaining only one adult from these eggs. This adult emerged on March 18 from a borer egg in which the parasite oviposited between February 27 and March 2, thus requiring between 16 and 19 days from the time of oviposition to the emergence of the adult, which is considerably longer than the time required for Trichogramma. On March 17, 36 black eggs were sent to New Orleans. Later, on May 13, 108 clusters were forwarded, 95 collected in Guemes and 13 in Tucuman. The majority of these were parasitized by Trichogramma, but a few appeared to be parasitized by Telenomus. No Telenomus adults were obtained from this material, but Trichogramma emerged, showing that they at least were not killed by the cold storage en route.

In 1930 a few parasitized eggs were seen in Guemes about the middle of February, but collections were not made until the first

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week in March. All the clusters obtained were examined under a binocular in order to separate those parasitized by Telenomus from those parasitized by Trichogramma. In table 2 are given the results of these examinations. In 520 clusters, containing 5,118 eggs, 72.5 percent were parasitized by Trichogramma and 26.3 percent by Telenomus.

TABLE 2.—*Relative parasitization of eggs of Diatraea saccharalis by Trichogramma minutum and by Telenomus alecto, Guemes, Argentina, 1930*

Species	Eggs examined	Unparasitized eggs		Parasitized eggs			
				Already emerged	Not yet emerged	Total	
	Number	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*
Trichogramma minutum				1,530	2,182	3,712	72.5
Telenomus alecto				451	893	1,344	26.3
Total	5,118	62	1.2	1,981	3,075	5,056	98.8

From this material 80 clusters, containing 611 eggs parasitized by Telenomus, were sent by airplane from Buenos Aires to New Orleans on March 11. A few parasites emerged from this shipment, but did not oviposit on the borer eggs furnished to them. Adults emerged from the eggs retained at Tucuman for rearing work, but they failed to oviposit, though they were kept under the same conditions as those of the previous year, when oviposition did occur.

Later, during the first week of April, 1930, when a large number of parasitized egg clusters were examined at Guemes, not one was found to be parasitized by Telenomus. This species apparently reaches its peak of abundance about the middle of the growing season, much sooner than Trichogramma. That more are not found later may be due to the rapid increase of Trichogramma towards the end of the season.

Telenomus is much larger than Trichogramma and only one individual emerges from a single Diatraea egg, whereas three or more Trichogramma usually emerge from one Diatraea egg.

Telenomus was found most numerous in Guemes, where *Diatraea dyari* Box was the prevalent host species. This host is much larger than *D. saccharalis*, and it may be that the eggs of the latter are somewhat too small to provide sufficient food for Telenomus. This may explain why the parasite is not more abundant where *D. saccharalis* occurs alone.

During the last half of January and the first week in February 1931 some 15,000 Diatraea egg clusters were collected in Peru in the search for *Telenomus alecto*. Of this number 4,634 were collected around Trujillo, 4,047 at Cartavio, 4,770 near Chiclayo, and 1,622 near Cayalti. The majority contained parasitized eggs from which the parasites had not emerged, as the collectors were instructed not to bring in dried-up or emerged clusters. From these egg clusters thousands of *Trichogramma minutum* emerged, but not a single Telenomus.

Telenomus alecto also occurs in British Guiana, Barbados, Trinidad, St. Vincent, Santa Lucia, and Puerto Rico.

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TRICHOGRAMMA MINUTUM RILEY

The familiar egg parasite *Trichogramma minutum* was found to be present in both Argentina and Peru, but no special studies of it were made.

It was noticed in Argentina that the parasitization varied considerably in different sections during the same year and also from one year to another. During the first season Trichogramma was very scarce in Tucuman. Twelve egg clusters were found on February 24, 1929. One cluster had been parasitized by Trichogramma and the parasites had emerged, borer larvae had emerged from 5 clusters, and the remaining 6 contained larvae ready to hatch. That season it was abundant at Guemes, whereas during the following season it was abundant in both localities. The percentage of parasitization was highest toward the end of the growing season.

In Peru it is usually very abundant in older cane, and the percentage of parasitization is very high, but in young cane it is usually scarce.

Normally 3 or more Trichogramma emerge from 1 Diatraea egg. In one case 14 were reared from 2 eggs of the borer.

APANTELES XANTHOPUS (ASHM.)

A number of small white Apanteles cocoons were found in splitting open cornstalks in Tucumán for borer parasites. More of these were found during the last of March and the first of April than at any other time, and the majority of the cocoons were empty. Only one cocoon was found in each tunnel, and this tunnel was usually very small and very close to the side of the stalk. This would indicate that the parasite attacks the very small borers shortly after they eat into the stalk, or possibly even before they actually enter it.

A few live pupae in cocoons were found, and from one collected on March 28, 1929, a female emerged the next day. One collected on May 31 also produced a female some time later. These adults were determined by R. A. Cushman to be *Apanteles xanthopus* (Ashm.)

NEMATODA

Five specimens of mermithids obtained from Diatraea borers cut from corn in Tucumán were sent to Washington for and identified by G. Steiner as *Hexamermis microamphidis* Steiner.

Four of these mermithids were found on February 5, 1929, in cane that had previously been infested with borers obtained from corn. The fifth was obtained on January 16, 1929, from a borer that was found in corn on January 9. Only 7 parasitic worms were found in more than 3,000 borers removed from corn and held for observation. It is evident that the percentage of parasitization by this species is very low.

FUNGI

Dead borers entirely covered with a white fungus were found in cane and corn in Argentina. Specimens of these fungi were submitted to Washington for identification. Vera K. Charles, of the Bureau of Plant Industry, stated that two species of fungi were present, but a species of Botrytis tentatively identified as *Botrytis*

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delacroixii Sacc. (family Mucedineae) seemed to be the predominant one.

Some borers that appeared to be healthy and had been placed in cane developed a fungus disease. This fungus was later identified as *Mucor botryoides* Lendner (family Mucoraceae) by Miss Charles, who stated: "This species, or varieties of it, have been reported as parasitic, but this is our first experience with it on this host, and therefore especially interesting."

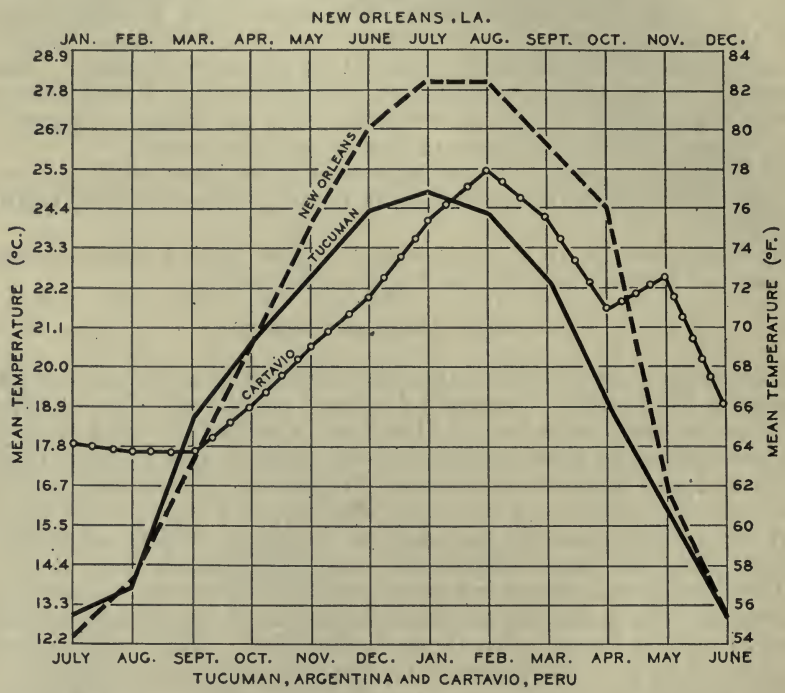

FIGURE 9.—Mean monthly temperatures at Tucuman, Argentina, Cartavio, Peru, and New Orleans, La. Temperatures recorded for 10 years at Tucuman and Cartavio and for 60 years at New Orleans.

The percentage of borers showing fungous attack was very small, but when weather conditions are suitable such attacks may help considerably in reducing the borer infestation.

CLIMATIC CONDITIONS IN THE MAIN FIELDS OF INVESTIGATION

In comparing the monthly mean temperatures (fig. 9) of Tucuman, Argentina, Cartavio, Peru, and New Orleans, La., as shown in records covering a long period of years, it is seen that New Orleans has a mean of 82.4° F. for its hottest month (July), while the mean for Tucuman's hottest month (January) is only 76.8°, or 5.6° less. For the coldest month New Orleans has a mean of 54.5°, which is 0.9° colder than the mean for Tucuman. However, in comparing the extreme temperatures of these two places, Tucuman records 111°, while New Orleans records only 102°. In winter New Orleans is several degrees colder than Tucuman, sometimes as low as

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20° and on very rare occasions still lower, while Tucuman seldom reaches a temperature lower than 26°. Cartavio, Peru, with 77.9° as its mean for the hottest month (August), is intermediate between New Orleans and Tucuman, being 1° warmer than the latter; however, it never reaches the extremely high temperaturs of Tucuman, the maximum being 100°. The mean temperature for the coolest month in Cartavio is 63.6°, which is some 9° higher than that for New Orleans. The freezing point is never reached in Trujillo, Peru, the recorded minimum being 46°.

New Orleans has a more or less even rainfall through the year, with an average of 4.7 inches per month. The warmer months of June, July, and August show a slight increase over the winter

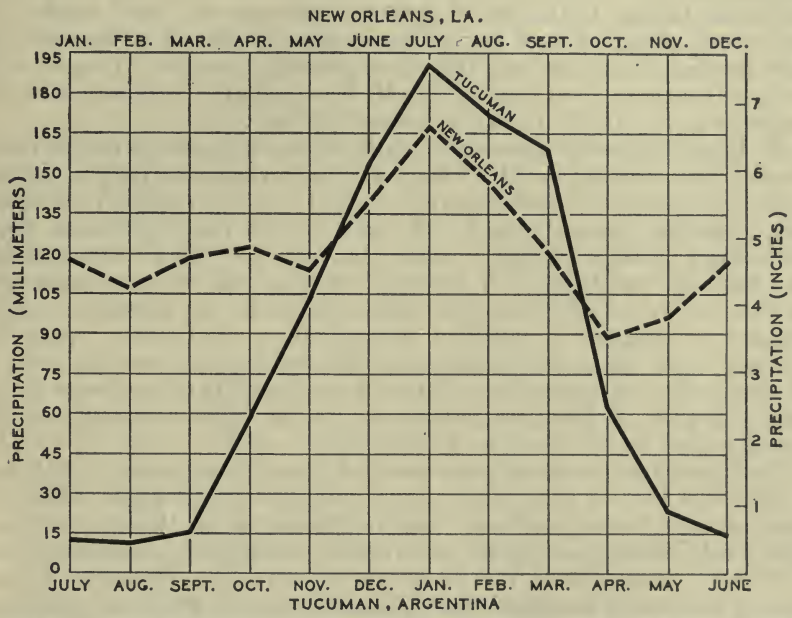

FIGURE 10.—Curves comparing the seasonal mean monthly precipitation at Tucuman, Argentina, with that at New Orleans, La. Precipitation recorded for 34 years at Tucuman and 83 years at New Orleans.

months. The average total rainfall per year (average for a period of 83 years) is 57.3 inches.

In Tucuman there are distinct wet and dry seasons, with approximately four fifths of the rainfall for the entire year occurring during the warm months from November to March, inclusive. From May to September, inclusive, the average rainfall is only one half inch per month. The average rainfall per year (average covering a period of 34 years) is 38.4 inches, which is 19 inches less than the average at New Orleans (fig. 10).

The coastal district of Peru is said to be rainless, though there is a slight precipitation occasionally. Heavy mists often occur, and the air is humid rather than arid. No records showing the relative humidity are available for comparison with records of the other stations under consideration.

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AGRICULTURAL PRACTICES IN THE SUGARCANE DISTRICTS OF ARGENTINA AND PERU

The agricultural practices used in growing and handling the sugarcane crop in Peru and Argentina differ very greatly, largely because of climatic conditions.

The length of the growing season in Argentina is similar to the length of that in Louisiana, about 7 months; in both there is a nongrowing period due to low temperatures. The Argentine grinding season usually lasts about four months, beginning the middle of May or the first part of June, and extending into September or October, at which time the heavy rains begin, and the roads become impassable for the heavy 2-wheeled carts used to carry the cane from the field to the mill. In Argentina the cane is cut "white" or unburned, stripped, and topped, and later the trash is burned. In the northern portion of the cane-growing section irrigation is largely practiced, but farther south less irrigation is used, and the crop there is dependent on the actual rainfall.

In Peru the growing season is continuous, as the temperature never reaches the freezing point. However, the cane grows very little during the cool season and requires from 14 to 20 months to mature. The grinding season also is continuous, and the mills shut down only for necessary repairs. Here the cane is "fired" to eliminate the work of stripping. It is then cut and topped, and loaded on railroad cars which are run into the fields on portable tracks. Sugarcane culture is entirely dependent on irrigation from the rivers, which have their sources in the mountains; no rain falls in the cane-producing section. Cane, as well as all other crops in the coastal region of Peru, is grown only in the valleys through which water comes down from the mountains.

In Argentina practically no use is made of commercial fertilizers, whereas in Peru a very large quantity of guano is used. The varieties of cane grown in Peru, the soft kinds such as Bourbon, Cristalina, and Caledonia, appear to be more extensively attacked by the borer than do the hard P.O.J. 36 and 213 varieties grown in Argentina. It is also thought that in some cases in Peru an excess of fertilizer and water has made the cane softer and thus more readily damaged by the borer.

SUMMARY

Eleven species of parasites, including a nematode and two fungi, were found attacking the sugarcane borer (*Diatraea saccharalis*) in Argentina and Peru. The insects include 2 species of flies (1 dexiid and 1 tachinid) and 6 species of wasps (4 braconids, 1 trichogrammatid, and 1 scelionid).

The dexiid fly *Paratheresia claripalpis* is the most common parasite, both in Argentina and Peru. It has several generations a year in both countries, and the parasitization in the young cane (dead hearts) was found to range from 2 to 74 percent, with an average of about 32 percent. The percentage of parasitization in the older cane was found to be considerably lower. The climatic conditions under which this species lives in Argentina are similar to those of Louisiana. A total of 637,063 puparia were shipped from

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Argentina and Peru during the three seasons. Ten secondary parasites were encountered.

The tachinid *Leskiomima jaynesi* was found only in Tucuman, Argentina, and in very small numbers. It appears to be localized, and not enough specimens were obtainable for study or shipment. Its life history is apparently similar to that of *P. claripalpis.*

Two species of Ipobracon were found to be parasitic upon Diatraea larvae; *I. tucumanus* in Argentina, of which 421 cocoons and 235 adult females were shipped during the first two seasons, and *I. rimac* in Peru, of which 59,632 adult females were shipped during the three seasons. Although *I. rimac* was present in large numbers in the cane fields, it never caused great parasitization.

Bassus stigmaterus was found in small numbers in both Argentina and Peru and only during the warmest months. On one occasion parasitization by this species was found to attain 9.7 percent. Only 127 cocoons of this species were shipped from Argentina during the first two seasons.

A scelionid, *Telenomus alecto*, was found in fairly large numbers, but only in the Province of Salta, Argentina, where *Diatraea dyari* occurs. This parasite will attack eggs of *D. saccharalis* and develop in them, but it was not found in eggs collected in localities where only *D. saccharalis* occurs. In 1929, 36 Diatraea eggs parasitized by this species in the laboratory and 108 field-collected parasitized egg clusters were sent to New Orleans. In 1930, 80 field-collected clusters containing 611 eggs parasitized by this species were sent by airplane.

Trichogramma minutum occurs in both Argentina and Peru and is quite effective, although it does not accomplish a high degree of parasitization until the latter part of the season, which is also true of this parasite in Louisiana.

Only two adults of *Apanteles xanthopus* were reared from cocoons found in small borer tunnels.

A few of the nematodes *Hexamermis microamphidis* were reared from borers in Argentina. The percentage of parasitization was extremely small.

Two fungi were found, *Botrytis delacroixii* and *Mucor botryoides*, but both are apparently of minor importance. No special effort was made to ship borers covered with fungus other than those sent for identification.

LITERATURE CITED

(1) ALDRICH, J. M.
1932. NEW DIPTERA, OR TWO-WINGED FLIES, FROM AMERICA, ASIA AND JAVA, WITH ADDITIONAL NOTES. U. S. Natl. Mus. Proc., v. 81, art. 9, 28 p., illus.

(2) BOX, H. E.
1927. APUNTES PRELIMINARES RESPECTO AL DESCUBRIMIENTO DE ALGUNOS PARÁSITOS DE LOS HUEVOS DE "DIATRAEA SACCHARALIS" EN TUCUMÁN. Rev. Indus. y Agr. Tucumán 18: [5]–8, illus.

(3) ———
1927. LOS PARÁSITOS CONOCIDOS DE LAS ESPECIAS AMERICANAS DE "DIATRAEA," (LEPIDOPTERA, PYRALIDAE). Rev. Indus. y Agr. Tucumán 18: [53]–61.

(4) BURGESS, A. F., and CROSSMAN, S. S.
1929. IMPORTED INSECT ENEMIES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH. U. S. Dept. Agr. Tech. Bul. 86, 148 p., illus.

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(5) HOLLOWAY, T. E., HALEY, W. E., and BYNUM, E. K.
1932. RECEIVING PARASITES OF THE SUGARCANE BORER IN LOUISIANA. Jour. Econ. Ent. 25: 68–70.

(6) ——— HALEY, W. E., and LOFTIN, U. C.
1928. THE SUGAR-CANE MOTH BORER IN THE UNITED STATES. U. S. Dept. Agr. Tech. Bul. 41, 77 p., illus.

(7) JAYNES, H. A.
1930. NOTES ON PARATHERESIA CLARIPALPIS VAN DER WULP, A PARASITE OF DIATRAEA SACCHARALIS FABR. Jour. Econ. Ent. 23: 676–680.

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Technical Bulletin No. 364 June 1933

THE COMPOSITION AND DISTRIBUTION OF PHOSPHATE ROCK WITH SPECIAL REFERENCE TO THE UNITED STATES

BY

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and

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Fertilizer and Fixed Nitrogen Investigations
Bureau of Chemistry and Soils

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 364 JUNE 1933

UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C

THE COMPOSITION AND DISTRIBUTION OF PHOSPHATE ROCK WITH SPECIAL REFERENCE TO THE UNITED STATES

By K. D. JACOB, *Chemist*, and W. L. HILL, H. L. MARSHALL, and D. S. REYNOLDS, *Assistant Chemists, Division of Fertilizer Technology, Fertilizer and Fixed Nitrogen Investigations, Bureau of Chemistry and Soils.*[1]

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INTRODUCTION

Phosphate rock is the most important of the mineral fertilizer materials, in annual tonnage handled.

The domestic phosphate-rock industry dates from 1867, when mining of the South Carolina deposits began. Since then the annual produc-

[1] The authors express to L. F. Rader, Jr., their appreciation for assistance in the chemical analyses; to S. B. Hendricks and M. E. Jefferson, of the physics and physical chemistry division, for the X-ray and microscopical examinations of the samples; to L. T. Alexander and Hubert Lakin, of the soil chemistry and physics division, and to Mrs. Dorotha M. Darnell, formerly of the same division, for the mechanical analyses and the preparation of the mechanical separates; to G. R. Mansfield, United States Geological Survey, and to B. L. Johnson, United States Bureau of Mines, for criticism of the manuscript; and to the phosphate mining companies and fertilizer manufacturers, who furnished the majority of the samples used in this investigation.

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tion has increased, more or less steadily, to an average of approximately 3,000,000 long tons at present. During this more than half a century phosphate-mining activities have shifted from the comparatively low-grade South Carolina deposits to the richer Florida and Tennessee deposits. Comparatively small tonnages are also produced annually from the deposits in Idaho, Montana, and Wyoming, which perhaps constitute the largest known reserve of high-grade phosphate rock in the world. From time to time small quantities of phosphate have been mined in other States, notably Alabama, Arkansas, Kentucky, Pennsylvania, and Utah. Deposits of limited extent are also known to occur elsewhere in the United States.

Aside from the part played by phosphate mining in contributing to the wealth of the United States, phosphate rock has formed the basis of the domestic chemical-fertilizer industry from the time of its establishment (about 1850). This industry now consumes approximately 2,000,000 long tons of phosphate rock annually in the manufacture of approximately 4,000,000 short tons of phosphate fertilizers, principally superphosphate. In addition to this approximately 300,000 long tons of rock are used annually in the manufacture of elemental phosphorus, phosphate chemicals, and blast-furnace products; as an ingredient in livestock and poultry feeds; and for direct application to the soil as a fertilizer. The annual exports of phosphate rock amount to approximately 700,000 long tons.

Although phosphate rock is valued primarily for its content of phosphoric acid, the commercial desirability of a particular grade or type of rock may be affected to a certain extent by the presence of admixed impurities such as silica, carbonates, aluminum, iron, etc. Phosphate rock containing more than about 5 to 6 percent of total oxides of iron and aluminum is not considered desirable for the manufacture of superphosphate, principally because of the poor mechanical condition of the resulting product. Rock of very high iron content is also undesirable for the manufacture of phosphoric acid by furnace processes because of the formation of iron phosphide, a material for which there is only a limited demand and which is relatively difficult to convert into other phosphate products.

In the manufacture of superphosphate, the presence of about 1 to 3 percent of carbon dioxide in the phosphate rock is desirable because the liberated carbon dioxide renders the superphosphate porous and spongy, and thereby facilitates drying. Larger percentages of carbon dioxide are not desirable, however, because of the increase in the amount of sulphuric acid required to obtain satisfactory conversion of the phosphoric acid into available forms.

Other than its action as a diluent, silica has no harmful effect on the use of phosphate rock for the manufacture of superphosphate and other products. On the other hand, high-silica rock may possess some advantage in the manufacture of phosphoric acid by furnace processes, inasmuch as a certain ratio of lime to silica must be maintained in the furnace charge in order to produce a slag which may readily be tapped from the furnace.

As shown by recent investigations (*64*),[2] fluorine is an essential component of the complex phosphates occurring in all types of domestic phosphate rock, and in nearly all commercially important types

[2] Italic numbers in parentheses refer to Literature Cited, p. 79.

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of rock from foreign deposits. Sufficient evidence is now available to justify the conclusion that the conversion of the phosphoric acid of phosphate rock into a condition that will permit its ready utilization as plant food is dependent upon the extent to which the complex phosphate-fluorine compound is decomposed by the processing treatment. From the standpoint of the fertilizer manufacturer, fluorine was formerly considered an undesirable constituent of phosphate rock, because the fluorine-bearing gases generated during the manufacture of superphosphate created a nuisance in the vicinity of the factories. Today, however, many superphosphate plants are utilizing these gases for the production of hydrofluosilicic acid and fluosilicates. Because of the deleterious effect of fluorine on the health of animals (*7*, *107*, *147*), its presence in phosphate rock has prevented the general use of this cheap source of calcium and phosphorus in mineral mixtures for livestock feeding.

Among the constituents of phosphate rock, calcium is next in importance to phosphoric acid. Recent investigations (*52*) have shown that normal growth of tobacco cannot be obtained on certain soils, particularly sandy and sandy loam soils, without the application of calcium compounds. The compounds present in superphosphate and in double or triple superphosphate are effective sources of calcium for such soils. The fertilizers used on these soils in the past always contained calcium in the form of superphosphate, and evidence of calcium deficiency was not obtained until the new types of calcium-free fertilizers were used.

During recent years considerable attention has been given to the effect on plant growth of the so-called less common elements, such as manganese, copper, zinc, chromium, vanadium, arsenic, iodine, etc. (*103*, *171*). Certain of these elements occur in phosphate rock and, aside from their possible effect on plant growth, may have an important bearing on the use of the rock in the manufacture of phosphates for food and technical purposes, so far as they impart undesirable properties to the finished products. If the phosphates are to be used in the manufacture of food products, it is also important that the content of certain impurities, such as arsenic and lead, shall not exceed the limits prescribed by the various State and Federal pure-food regulations.

It is evident from the foregoing that a thorough knowledge of the complete chemical composition of the various commercial types of phosphate rock occurring in the United States is an aid in their rational use for the manufacture of fertilizers and phosphate chemicals and for other purposes. This information is also valuable in the study of the chemical structure of phosphate rock, a thorough knowledge of which is essential to an understanding of the reactions occurring during processes in the manufacture of available phosphates. Despite their importance, comprehensive data on the chemical composition of domestic phosphate rock are not available. Except for occasional incomplete analyses of isolated samples, usually selected materials or prospect samples, the sparse data recorded in the literature before the beginning of the present investigation relate principally to the occurrence of phosphoric acid, calcium, aluminum, and iron.

The results presented in this bulletin comprise more or less complete chemical analyses of all the domestic types of phosphate rock which are of commercial interest at present. Special attention is given to

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the occurrence of fluorine, iodine, and the so-called less-common metallic elements, such as manganese, chromium, vanadium, copper, zinc, and arsenic; to the chemical composition of the mechanical fractions separated from natural phosphates; and to the solubility of natural phosphates in ammonium-citrate and citric-acid solutions.

In order to present a comprehensive picture of the phosphates of the United States, it is important to give a brief review of the deposits and the production and reserves of rock before discussing the results of the chemical analyses.

REVIEW OF PHOSPHATE DEPOSITS OF THE UNITED STATES

ALABAMA

Deposits of phosphatic greensand and phosphatic nodules and shell casts occur in Alabama in a belt extending southward 20 to 50 miles from a line drawn from Columbus, Ga., westward through Tuskegee, Montgomery, Marion, Greensboro, and Eutaw, Ala., on to Columbus, Miss. (*137*, *183*, *184*, *192*). Deposits of phosphate also occur in Limestone County, just south of the Tennessee line, along Elk River, Sugar Creek, and Little Shoal Creek (*105*, *165*; *185*, *p. 64*). According to Phalen (*138*), a deposit of aluminum phosphate (wavellite) is reported to exist near Mitchell Mountain, on the Coosa River, 6 miles east of Coal City, St. Clair County. In general, the Alabama phosphates are comparatively low in phosphoric acid and occur in small, irregular deposits. Consequently, the deposits have not been worked on a large scale, although before 1901 small quantities of rock were mined in certain localities.

ARKANSAS

Deposits of phosphate rock extend over a considerable area in north-central Arkansas (*11*, *12*, *140*, *146*, *196*), and the phosphate horizon has been recognized in Independence, Stone, Izard, Searcy, Marion, Baxter, and Newton Counties. The only deposits that have been developed commercially are those on Lafferty Creek, Independence County, near the junction of East Lafferty and West Lafferty Creeks, about 4 miles southwest of Cushman. These deposits have not been worked, however, since 1915. In general, the Arkansas phosphates contain less phosphoric acid and more iron and aluminum than the Tennessee phosphates, and many of the deposits are located at some distance from railroad lines. These factors have operated against their commercial development, but the deposits constitute an important phosphate reserve for the Middle-Western agricultural region.

FLORIDA

Since 1890 the Florida phosphate deposits (*93*, *113*, *122*, *126*, *140*, *176*, *177*, *195*, *208*, *209*) have been of great importance to agriculture, not only in the United States but in European and other foreign countries.

Four principal varieties of phosphate occur in Florida. In the order of their present importance these are land-pebble phosphate; hard-rock phosphate; claylike phosphates, including the soft and waste-pond phosphates; and river-pebble phosphate. Phosphatized limestone and phosphatic marl also occur in certain localities (*122*).

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The land-pebble phosphate deposits are by far the most important in Florida, and, from the standpoint of production, they have been the most important in the United States since 1905. The deposits cover a considerable area in the eastern and western portions of Hillsborough and Polk Counties, respectively, and extend southward into the northeastern corner of Manatee County and the northwestern corner of Hardee County. At present the principal producing mines are located near Bartow, Brewster, Coronet, Lakeland, Mulberry, Nichols, and Pierce.

The hard-rock phosphate deposits occur in a belt that extends southward from Suwannee and Columbia Counties, through portions of Gilchrist, Alachua, Levy, Marion, Citrus, Sumter, and Hernando Counties, to Pasco County—over 100 miles. Deposits are also known in Lafayette, Taylor, Jefferson, Wakulla, and Liberty Counties. Deposits of plate rock, a variety of hard-rock phosphate, occur in central Marion County near Sparr, Anthony, and Ocala. Mines have been operated in nearly all sections of the hard-rock phosphate region, but since 1925 only certain deposits near the towns of Dunnellon, Inverness, and Hernando have been worked.

For the purpose of this bulletin, the claylike phosphates of Florida are divided into two classes, namely, soft phosphate and waste-pond phosphate (*71*, *85*, *122*). Soft phosphate is commonly closely associated with both the land-pebble and hard-rock phosphates, but it occurs to a greater extent in the hard-rock deposits. It is not only present in the matrix of the hard-rock and land-pebble phosphates, but Mansfield (*113*) states that soft phosphate occurs in more or less isolated pockets in the Vicksburg limestone and in larger areas scattered over several square miles northwest of Ocala, Marion County, and in Pasco County, south of Greer and southwest of Richland. Since 1889 small quantities of soft phosphate have been mined from time to time and sold principally for direct application to the soil.

During the process of preparing hard-rock phosphate for the market the soft phosphate in the matrix is washed into waste ponds, where it settles out with the clay and other impurities, the finer particles concentrating at points farthest from the entrance to the ponds. The abandoned waste ponds in the hard-rock district contain a considerable tonnage of this material, which analyzes as high as 25 percent phosphoric acid. The waste ponds in the land-pebble district contain smaller percentages of finely divided phosphate than do the hard-rock waste ponds. In this publication the finely divided phosphate deposited in the hard-rock phosphate waste ponds will be referred to as waste-pond phosphate in order to distinguish it from the soft phosphate obtained directly from the original deposits. For the last several years, small tonnages of waste-pond phosphate have been recovered annually from abandoned waste ponds in the hard-rock district, principally near the town of Dunnellon, and sold for direct application to the soil.

According to Matson (*122*), river-pebble phosphate was first mined in 1888 on Peace River near Arcadia, De Soto County, and later along Peace River from Mulberry, Polk County, southward. Mining was also done near Fort Ogden and Hull, De Soto County, on

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Alafia River, and in Clay County on Black Creek, a tributary of St. Johns River. River-pebble deposits have also been reported on Manatee, Miakka, Kissimmee, and Caloosahatchee Rivers and at the mouth of Fisheating Creek. No river-pebble phosphate has been mined since 1914.

GEORGIA

According to McCallie (*106*), deposits of phosphatic marl in Georgia are widely distributed in the counties lying along the Georgia-Florida State line. Deposits of phosphate rock have been discovered in Thomas County, near the towns of Boston and Thomasville, and, according to Day (*41*), in Glynn County at the headwaters of the Little Satilla River. Because of the limited quantity of phosphate and the high mining costs, the deposits were worked only at irregular intervals before 1900. Phosphatic nodules, of no economic importance, occur in Floyd and Chattooga Counties, embedded in the Chattanooga shale (*60*).

IDAHO

The Idaho deposits constitute one of the largest known reserves of high-grade phosphate rock in the world. The known deposits lie in the southeastern part of the State in Bear Lake, Bannock, Caribou, Bingham, Bonneville, Madison, Teton, Fremont, and Clark Counties (*51, 113, 114, 118, 119, 154, 155, 173, 175, 194*). Those thus far studied in detail are located in the Montpelier, Crow Creek, Freedom, Slug Creek, Lanes Creek, Henry, Crane's Flat, and Portneuf quadrangles, and in the Fort Hall Indian Reservation. In 1930, deposits were being worked near Conda, Caribou County, and Paris, Bear Lake County. Phosphate rock has also been mined near Montpelier, Bear Lake County.

ILLINOIS

Phosphate deposits in Illinois occur immediately above the Maquoketa shale in the southern portion of Calhoun County (*97, 205*). Although these deposits have not been investigated, it is quite probable that they are not commercially valuable at the present time.

KENTUCKY

Phosphate deposits are known to occur in Kentucky in the vicinities of Midway, Versailles, and Wallace, Woodford County; Lexington, Fayette County; Georgetown, Scott County; near the Forks of Elkhorn, Franklin County; and near Pine Grove Station, Clark County (*49, 139, 140, 196*). Deposits of phosphatic limestone occur directly below the phosphate rock horizon. The richest deposits of phosphate rock, which occur in the area around Wallace and Midway, were worked for several years prior to 1927.

MASSACHUSETTS

In Massachusetts, phosphate nodules of no commercial importance occur in the tertiary greensand beds exposed in the cliffs at Gay Head, Martha's Vineyard (*137, 178*). Small quantities of apatite are said to occur at Bolton, Worcester County (*206*).

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MISSISSIPPI

Deposits of phosphatic marl in Mississippi occur in Tippah, Tishomingo, Pontotoc, Itawamba, Chickasaw, Monroe, Oktibbeha, Lowndes, Noxubee, Kemper, Hinds, and Lauderdale Counties (*41*), but none of these deposits is of commercial importance at present. Beds of phosphatic nodules, similar to those in Alabama, are said to occur in Mississippi.

MONTANA

The known Montana phosphate deposits (*35*, *50*, *113*, *133*, *134*, *135*, *156*, *189*) occur in the vicinities of Philipsburg and Maxville, Granite County; Elliston and Garrison, Powell County; and Melrose, Silver Bow County. Deposits are also known in Deer Lodge, Beaverhead, Gallatin, Madison, and Lewis and Clark Counties. The most important deposits are located in the Elliston, Garrison, and Philipsburg districts. In 1930, mining operations were started near Garrison and Philipsburg. A small quantity of phosphate has also been mined from the Maxville deposits.

NEVADA

According to Stone (*188*), deposits of phosphate rock have been reported in Nevada. Specimens of low-grade rock have been found near Ely and Osceola, White Pine County, and near Ocala and Huxley, at the south end of Humboldt Lake, Churchill County.

NEW JERSEY

Small deposits of massive apatite are said to occur at Hurdtown, Sussex County, N.J. According to Wilber (*206*), these deposits were mined to a small extent prior to 1882.

NEW MEXICO

No phosphate-rock deposits have been discovered in New Mexico, but deposits of bat guano occur in the southern part of the State and shipments have been made from those near Lava, Socorro County (*142*).

NEW YORK

According to Wilber (*206*), a deposit of massive apatite occurs in New York at Crown Point, Essex County. This deposit was mined to a small extent prior to 1882. Apatite also occurs in St. Lawrence County. Unsuccessful attempts have been made to separate, on a commercial scale, the apatite that is associated with the magnetite in deposits at Mineville, Essex County (*140*).

NORTH CAROLINA

The phosphate-rock deposits of North Carolina (*27*, *37*, *38*, *40*, *113*, *137*, *141*) lie in a belt 15 to 20 miles wide, extending from the South Carolina line northeastward with the trend of the coast to the Neuse River, and with its southeastern boundary 20 to 25 miles from the coast line. The belt runs through the counties of Columbus, Bladen, Sampson, a corner of Pender, and through Duplin, and includes a small part of Lenoir, Jones, and Onslow Counties. De-

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posits of a conglomerate of phosphatic nodules and marl lie just below the phosphate-rock deposits and extend southward through Pender and New Hanover Counties nearly to the coast. The conglomerate deposits near Castle Hayne in New Hanover County, were worked for several years during the latter part of the nineteenth century. The scattered nature of the deposits and the high mining costs have prevented their extensive development. No phosphate rock has been mined in North Carolina since 1903.

OKLAHOMA

A small deposit of phosphate nodules has been discovered in Oklahoma in the extreme southeastern corner of Cotton County, just west of the Cotton-Jefferson County line (*179, 180*). Also, Reeds (*148*) reports the occurrence of phosphatic nodules in the Woodford shale and chert of the Arbuckle Mountains.

PENNSYLVANIA

Deposits of low-grade phosphate rock have been found in Pennsylvania at various points within 12 miles of Reeds Gap, Juniata County (*83*). The entire mass of detritus occurring in these localities between the Oriskany sandstone and the Onondaga limestone has been phosphatized to an extent varying from 3 to 12 percent of phosphoric acid. Deposits of aluminum phosphate (wavellite) occur at the foot of South Mountain, in the vicinity of Mount Holly Springs, 20 miles southwest of Harrisburg (*190*). These deposits were worked about 1905, and the ore was used for the manufacture of elemental phosphorus.

SOUTH CAROLINA

Production of phosphate rock from the South Carolina deposits, which were the first to be discovered in the United States, began in 1867, and for more than 50 years important quantities of phosphate were mined annually from these deposits (*80, 113, 126, 127, 137, 145, 163, 181, 197, 208, 209*). The South Carolina phosphates are usually divided into two classes, land rock and river rock, the first being the most important. The land rock occurs in a more or less irregular bed which represents the undisturbed phosphatized Edisto marl. The river rock probably consists in part of the original phosphatized Edisto marl and in part of fragments derived from the land deposits and concentrated on the river bottoms. Phosphate deposits occur in Berkeley, Dorchester, Charleston, Colleton, and Beaufort Counties in a seaboard zone, most of which is less than 30 miles wide, extending from the Broad River, Beaufort County, northward to a point about 20 miles beyond Charleston. Production of river rock ceased in 1910 and that of land rock in 1925.

TENNESSEE

From the standpoint of production, the Tennessee phosphate deposits rank second in importance in the United States, being exceeded only by the Florida deposits. Three distinct commercial varieties of phosphate rock are recognized in Tennessee. These are known as the brown-rock, blue-rock, and white-rock phosphates. All

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the important deposits of these varieties are in the western part of the central basin of Tennessee and in the valleys of the western part of the highland rim surrounding the basin. Deposits of another variety, ranging in color from white to brownish black, are found in Johnson County (*90*). This rock is characterized by a relatively high content of manganese, but it usually contains less than 30 percent of phosphoric acid, and, at present, is not of commercial importance. Phosphatic limestones, usually containing less than 20 percent of phosphoric acid, are widely distributed in Tennessee, usually in close association with the phosphate-rock deposits.

The principal deposits of brown-rock phosphate, the most important of the Tennessee phosphates, occur in Sumner, Davidson, Williamson, Hickman, Maury, Lewis, and Giles Counties (*62a, 81, 113, 140, 186, 196*). In 1930, mines were being operated in the vicinity of Mountpleasant, Spring Hill, Columbia, Century, Ridley, and Southport, in Maury County; Nashville, Davidson County; Wales, Giles County; and Twomey, Hickman County.

Two types of blue-rock phosphate, formerly known as black phosphate, are recognized. These are the bedded phosphates and the nodular or kidney phosphates. The deposits of bedded phosphate are the most important, although kidney phosphate has been mined in certain localities, notably near Boma, Putnam County (*129*). Blue-rock deposits are known in the western part of Maury County; the eastern part of Lewis County; along Duck River and on both sides of Swan Creek in Hickman County; near Fernvale Springs in the western part of Williamson County; and in the southern and northern parts of Perry and Wayne Counties, respectively (*60, 61, 62a, 81, 140, 186, 196*).

White-rock phosphate occurs in several widely separated localities in Perry and Decatur Counties (*60, 61, 62, 62a, 82, 123, 196*). Mines have been operated at Tomscreek, Perry County, and along the tributaries of Beech River, between Parsons and Decaturville, Decatur County. Although many of the deposits contain high-grade phosphate, they occur mostly in pockets, and the high cost of mining has prevented extensive development. No production of white-rock phosphate has been reported since 1915.

At least two geological formations of phosphatic limestone are recognized in Tennessee, namely, the Leipers formation and the Bigby formation. The Leipers limestone has been a factor of considerable importance in the formation of blue-rock phosphate and in many places it directly underlies these phosphate deposits. Bigby phosphatic limestone is widely distributed in the brown-rock phosphate area, and is the source of much of the brown rock, though some of the latter is also derived from the Leipers limestone. Although no ecomonical method has been devised for the manufacture of fertilizers from phosphatic limestone, it is used to some extent in the preparation of mineral feeds for poultry and stock.

TEXAS

Phosphate rock deposits have not been discovered in Texas, but the investigations of Shead (*179, 180*) indicate that deposits may occur in the Permian red beds of the Wichita formation, in northern Texas, and Schoch (*170*) reports the occurrence of phosphatic rocks in Bexar

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and Brewster Counties. According to Phillips (*142*), there are deposits of bat guano in caves distributed along a line extending southwest from Lampasas County to Uvalde and Edwards Counties. Guano deposits have been found in Lampasas, Burnet, Llano, Mason, Williamson, Blanco, Gillespie, Hays, Comal, Kerr, Medina, Uvalde, and Edwards Counties. Some of these deposits have been worked at various times.

UTAH

Phosphate rock is widely distributed in northeastern Utah (*8*, *51*, *113*, *174*, *194*). Deposits are known in the Crawford Mountains, Laketown, and Woodruff areas of Rich County; and the Weber River Canyon, Sheepherd Valley, and Beaver Creek areas, near Ogden, Weber County. On the north side of the Uinta Mountain Range, deposits occur in the Weber-Bear River and Henrys Fork areas of Summit County. On the south side of the range, deposits occur in the Provo-Duchesne River area of Wasatch and Duchesne Counties, and the Whiterock River-Brush Creek area of Duchesne and Uintah Counties. Deposits also occur in Morgan County. Small quantities of phosphate rock have been mined in Utah, principally in Rich County, but no production has been reported since 1920.

VIRGINIA

Deposits of low-grade phosphate have been observed in two localities in southwestern Virginia (*191*), namely, at the foot of the southeast slope of Clinch Mountain, 5 miles west of Saltville, and in Walker Valley at the east end of Brushy Mountain, 5 miles west of Marion. Nelsonite, a name given to a group of high titanium-phosphorus-bearing ores, occurs in Amherst and Nelson Counties, and, to a less extent, on the northwest slope of the Blue Ridge in Roanoke County (*140*, *191*, *204*). The phosphorus is present in these ores in the form of coarsely crystalline apatite. A large deposit of ilmenite nelsonite, the normal and most abundant variety, occurs in Amherst County, near Piney River, and is being worked for the recovery of titanium compounds and apatite (*1*).

WYOMING

Phosphate rock is widely distributed in the western part of Wyoming (*9*, *34*, *51*, *112*, *113*, *173*, *194*). Deposits are known in the Wind River, Owl Creek, and Shoshone Mountains; the Hoback, Gros Ventre, Teton, and Salt River Ranges; the Sublette Ridge, Beckwith Hills, and Cokeville areas; and in Snake River Canyon. Since 1906 phosphate rock has been mined from some of the deposits, principally those near Cokeville, Lincoln County.

PRODUCTION OF PHOSPHATE ROCK IN THE UNITED STATES

Data on the marketed production of phosphate rock in the United States, as of December 31, 1930, are given in table 1. The figures include rock used by the producers.

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TABLE 1.—*Total marketed production and reserves of phosphate rock in the United States, as of December 31, 1930*

Source and type of phosphate	Marketed production, including rock used by producers	First and last years of commercial production	Estimated reserves [1]
Florida:	*Long tons*		*Long tons*
Land pebble	[2] 52, 262, 745	1891 [3]	[4] >269, 000, 000
River pebble	1, 310, 075	1888, 1914	([5])
Hard rock	[6] 12, 175, 066	1889 [3]	8, 200, 000
Soft rock	94, 807	1890 [3]	([5])
Total	65, 842, 693		>277, 200, 000
South Carolina:			
Land rock	[7] 9, 253, 412	1867, 1925	8, 798, 000
River rock	4, 105, 205	1870, 1910	([5])
Total	13, 358, 617		>8, 798, 000
Tennessee:			
Brown rock	[8] 10, 803, 286	1896 [3]	[4] 10, 000, 000
Blue rock	[8] 1, 279, 650	1894 [3]	83, 340, 000
White rock	[8] 8, 617	1898 [9], 1915	([5])
Total	15, 282, 432		>93, 340, 000
Western States:			
Idaho	474, 584	1906 [3]	4, 997, 380, 000
Montana	6, 713	1921 [3]	391, 316, 000
Utah	18, 047	1907, 1920	326, 727, 000
Wyoming	60, 271	1907 [3]	115, 694, 000
Total	559, 615		5, 831, 117, 000
Alabama	844	1887 [9], 1900	([5])
Arkansas	31, 753	1900, 1915	20, 000, 000
Kentucky	113, 661	1911, 1926	863, 000
North Carolina	56, 585	1885 [9], 1903	([5])
Pennsylvania	3, 993	1899, 1904	([5])
Other States	70		([5])
Grand total	95, 250, 263		>6, 231, 318, 000

[1] Containing the equivalent of approximately 55 percent or more of tricalcium phosphate.
[2] Includes a small quantity of river-pebble and soft phosphate.
[3] Under production in 1930.
[4] This figure can be approximately doubled by the use of flotation, according to a private communication from James A. Barr, of the International Agricultural Corporation.
[5] Estimate not available.
[6] Includes a small quantity of soft phosphate.
[7] Includes a small quantity of river rock.
[8] This figure is low because separate data on the production of the different types of Tennessee phosphate are not available for the years prior to 1905.
[9] Approximate year of first production.

In the case of the Florida phosphates, the figures were compiled from the data given by Wright (*208*) for the years 1888 to 1891; from those given by Johnson (*91*) for the years 1900 to 1928; and from the various volumes of Mineral Resources of the United States for the other years. It should be pointed out that the figures for the different types of rock are only approximate owing to the fact that in some years they include small quantities of other types. For example, the figure for land-pebble phosphate includes a small quantity of river-pebble and soft phosphate, and the figure for hard rock includes a small quantity of soft phosphate.

The figures for South Carolina phosphate were compiled from data given by Johnson (*91*) and in Mineral Resources of the United States. An insignificant quantity of river rock is included with the land rock.

The figures for the Tennessee brown- and blue-rock phosphates were furnished by the United States Bureau of Mines.[3] Since separate

[3] The authors are indebted to B. H. Stoddard and B. L. Johnson for the compilation of these and other data furnished by the Bureau of Mines.

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data on the various types of Tennessee phosphate for the years prior to 1905 are not available, the figure for the total Tennessee production, which is compiled from Mineral Resources of the United States, is greater than the sum of the totals for the different types. The figure for white rock represents the production in 1905 to 1908, inclusive. The quantity of white rock mined prior to 1905 is not known, but with the exception of a small tonnage (amount unknown) in 1915, this type of phosphate has not been produced since 1908.

The figures for the western phosphates[3a] were compiled from data furnished by the Bureau of Mines and from those given in Mineral Resources of the United States. The figures for Arkansas and Kentucky were compiled from data given by Johnson (*91*) and in Mineral Resources of the United States, the last publication also furnishing the figures for Alabama and Pennsylvania.

With the exception of a production of 700 tons in 1892, as reported by Wright (*208*), the figure for North Carolina was compiled from data given in Mineral Resources of the United States. It should be pointed out, however, that the figure includes 40,400 tons of low-grade phosphatic conglomerate, of which 35,000 tons were sold for use in building streets and roads.

RESERVES OF PHOSPHATE ROCK IN THE UNITED STATES

Data relating to the estimated reserves of phosphate rock in the United States, as of December 31, 1930, are given in table 1. It is believed that these estimates are, as a general rule, very conservative, since they do not take into account the use of the flotation process for the recovery of marketable phosphate from low-grade materials which cannot be treated successfully by the ordinary methods of concentration.

In 1923, G. W. Holland, of the United States Geological Survey, investigated the reserves of Florida land-pebble phosphate and estimated that the field contained at that time more than 288,000,000 long tons of minable phosphate (*116, p. 250*). Approximately 19,000,000 long tons of land pebble were mined during 1924–30. Consequently, it is estimated that the reserves of this material amounted to more than 269,000,000 long tons, as of December 31, 1930. James A. Barr,[4] chief engineer of the International Agricultural Corporation, estimates that the reserves of land pebble have been further increased at least 100 percent by the development of the flotation process for the treatment of low-grade phosphate ores.

In arriving at the figure for reserves of Florida hard-rock phosphate, the estimate made by Phalen (*140*) in 1915 has been revised to allow for the rock mined since that time, the figure on mined production being supplied by the United States Bureau of Mines. Estimates on the reserves of river-pebble and soft phosphate are not available.

Based on an estimate made originally by Chazal (*29, p. 18*) in 1904, Mansfield (*117, p. 88*) estimated that the reserves of South Carolina land-rock phosphate amounted to 8,800,000 long tons as of December 31, 1924. Corrected for the amount of rock mined since that time, the figure becomes 8,798,000 long tons as of December 31, 1930. No estimate of the reserves of river rock is available.

[3a] The term "western phosphates", as used in this publication, refers to phosphate from Idaho, Montana, Utah, and Wyoming.

[4] Private communication.

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In 1915, Phalen (*140*) estimated that the reserves of brown-rock phosphate remaining in middle Tennessee amounted to approximately 4,000,000 long tons. According to figures furnished by the United States Bureau of Mines, however, approximately 6,500,000 tons of brown rock were mined from this region in 1916–30. The estimate of reserves of brown rock was made by James A. Barr, who writes as follows:[5]

> The following figures were compiled from available prospecting data and adding thereto probable tonnages in other phosphate areas.
>
> It is generally conceded that the quantity of commercial grade phosphate outside of contiguous blocks now being exploited, is quite limited and found mostly in scattered areas too small to justify economical mining unless we consider the lately developed flotation process. This, we estimate, more than doubles the tonnages.
>
> Without flotation, the brown phosphate reserves will probably not exceed 10,000,000 tons, but with beneficiation we estimate a total from 20,000,000 to 24,000,000 tons.

The estimate of reserves of Tennessee blue-rock phosphate is that made by Phalen (*140*), from which has been deducted the mined production of rock as reported by the Bureau of Mines for the period 1916–30. An estimate of the reserves of white-rock phosphate is not available, and no figures have been compiled to show the quantity of phosphate occurring in Tennessee in the form of phosphatic limestone.

In 1927, Mansfield (*119, p. 292*) published revised estimates of the phosphate rock available in the Western States. These estimates, which do not take into consideration the rock mined in the individual States, have been changed to allow for the marketed production of rock from the beginning of commercial operations through the year 1930. The figures on marketed production, most of which were furnished by the Bureau of Mines, approximate very closely those on mined production.

The figure on reserves of Arkansas phosphate is that given by Waggaman (*198*) in 1914, no later estimate being available. The estimate of reserves of Kentucky phosphate given by Mansfield in 1922 (*115, p. 116*) has been revised to allow for the phosphate mined since that year. Estimates of the phosphate reserves in Alabama, North Carolina, and Pennsylvania are not available, but the reserves in these States are, no doubt, comparatively insignificant.

FLOTATION OF PHOSPHATE ROCK

The use of flotation methods for recovering marketable phosphate from low-grade ores has been mentioned in the preceding paragraphs, with special reference to its effect on the reserve supply of phosphate rock in the United States.

The results of experimental investigations in the United States Bureau of Mines (*102*) have shown that by means of flotation Florida land-pebble phosphate washer waste, containing approximately 4.5 percent phosphoric acid and 85 percent insoluble material, principally silica, can be concentrated to yield a product containing approximately 32 percent phosphoric acid and 6 percent insoluble material, 83 percent of the phosphoric acid being recovered in the concentrate. Charles E. Heinrichs, of the Phosphate Recovery Corporation, states[5]

[5] Private communication.

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that in a typical 30-day period of commercial operation of the flotation process, concentrates averaging approximately 35.5 percent phosphoric acid and 6.5 percent insoluble material were produced from Florida land-pebble washer waste containing approximately 7.5 percent phosphoric acid.

Although flotation in the phosphate industry has thus far been used principally in the recovery of phosphate from high-silica Florida land-pebble washer waste, a commercial unit for treating Tennessee brown-rock phosphate has recently been erected. The concentration of this type of phosphate involves the removal of iron and aluminum compounds, as well as silica. Data furnished by Heinrichs (table 2) indicate the extent to which a commercial grade of Tennessee brown-rock phosphate sand can be improved by flotation. It will be noted that the treatment has resulted in the removal of a very considerable portion of the iron, aluminum, and silica but has had no significant effect on the carbon dioxide and fluorine. It is said, however, that carbonate not combined with the phosphate molecule can be removed by flotation. Attempts to remove fluorine have not been successful, since this element is present, as a general rule, only in combination with the phosphate molecule.

TABLE 2.—*Effect of flotation on the composition of Tennessee brown-rock phosphate sand*

Item	P_2O_5	Fe_2O_3	Al_2O_3	CO_2	F	SiO_2
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Composition before flotation [1]	32.32	3.34	2.20	1.30	3.15	10.21
Composition after flotation [1]	35.82	2.28	.84	1.42	3.47	4.56

[1] Data furnished by Charles E. Heinrichs, of the Phosphate Recovery Corporation.

The flotation process seems destined to play an important part in conserving the supplies of Florida land-pebble and Tennessee brown-rock phosphates. When the occasion arises, the process can, no doubt, be applied also to all other types of domestic phosphate rock.

DESCRIPTION OF SAMPLES

More or less complete analyses of 46 samples of mineral phosphate were made. The samples represented nearly all of the more important types and sources of this material in the United States. Similar analyses of samples of bone ash, chlorapatite, fluorapatite, and foreign phosphate rocks were made. Brief descriptions of these samples are given in the following paragraphs. Partial analyses of a large number of additional samples from deposits in the United States and foreign countries were made.

Florida land-pebble phosphate.—All samples of land-pebble phosphate were taken from materials that had been subjected to the washing and screening processes (*199*) customarily used in preparing this type of phosphate for the market. Unless stated otherwise, the samples were taken from commercial, kiln-dried materials.

Samples 439, 910, and 912. Deposits near Mulberry, Polk County. Sample 439 was representative of a shipment of 2,218 tons. Samples 910 and 912 were taken from 100-pound quantities of air-dried material.

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Samples 617 and 947. Deposits near Brewster, Polk County. These samples represented shipments of 4,700 tons and 150 pounds, respectively.

Sample 618. Deposit near Pierce, Polk County. Representative of a large shipment.

Samples 619 and 622. Deposits near Nichols, Polk County. Representative of large shipments.

Samples 627 and 898. Deposits near Lakeland, Polk County. Representative of large shipments.

Sample 790. The location of the deposit from which this sample came is unknown, but it was in either Polk County or Hillsborough County. The sample was taken from about 25 tons of material.

Florida hard-rock phosphate.—Unless stated otherwise, the samples of hard-rock phosphate were taken from washed, screened, and kiln-dried materials.

Sample 434. Deposits near Dunnellon, Marion County. This sample was a composite of several samples representing large shipments.

Sample 589. Deposit near Floral City, Citrus County. Representative of a 3,500-ton shipment.

Sample 771. The location of the deposit from which this sample came is unknown. Nor is it known whether the sample was taken from commercial, washed and screened material, or from unwashed material.

Sample 932. Deposit near Dunnellon, Marion County. Representative of a 200-pound quantity of air-dried material.

Florida soft phosphate.—The term soft phosphate is used to designate the claylike phosphate obtained directly from the original deposits (p. 5). Unless stated otherwise, the samples were taken from noncommercial air-dried materials.

Sample 443. Deposit in Gilchrist County, about 7 miles west of Fort White and 3 miles south of the Santa Fe River.

Sample 580. Deposit in the hard-rock phosphate district. The location of the deposit is not known.

Sample 728. Deposit near Juliette, Marion County.

Sample 1091. Deposit near Bartow, Polk County. Representative of a 100-pound quantity of commercial kiln-dried material, which had not been subjected to washing and screening operations. Soft phosphate has been produced from this deposit on a commercial scale for several years.

Florida waste-pond phosphate.—The term waste-pond phosphate is used to designate the very finely divided claylike phosphatic material obtained from the waste ponds of hard-rock phosphate-washing plants (p. 5). Unless stated otherwise, the samples were taken from air-dried materials.

Sample 726. Abandoned waste pond near Felicia, Citrus County.

Sample 727. Abandoned waste pond near Dunnellon, Marion County. This sample and no. 726 came from waste ponds from which comparatively small quantities of material have been marketed in recent years.

Sample 915. Abandoned waste pond near Dunnellon. Representative of a 100-pound quantity of commercial kiln-dried material.

Tennessee brown-rock phosphate.—Unless stated otherwise, the samples of brown-rock phosphate were taken from commercial, washed and kiln-dried materials.

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Sample 56. Location of deposit unknown. This material is Bureau of Standards standard sample no. 56, which is widely used as a reference standard in the determination of calcium, phosphorus, aluminum, and iron in phosphate rock.

Samples 564, 587, and 906. Deposits near Wales, Giles County. The material from which no. 587 was taken is known as "cone sand", one of the finer sizes of rock obtained during the washing process. No. 906 was taken from a 100-pound quantity of air-dried material.

Samples 762 and 908. Deposits near Mountpleasant, Maury County. No. 908 was taken from a 100-pound quantity of air-dried material.

Tennessee blue-rock phosphate.—Unless stated otherwise, the samples of blue rock used in this investigation came from deposits of the bedded variety of phosphate (p. 9).

Samples 448 and 772. Deposit at Glover, Lewis County. Commercial air-dried materials.

Samples 449 and 930. Deposit near Gordonsburg, Lewis County. No. 449 was taken from commercial kiln-dried material. No. 930 was representative of a 200-pound quantity of air-dried material.

Sample 1049. Air-dried kidney phosphate from a deposit near Boma, Putnam County. Kidney phosphate was formerly mined in this locality.

Tennessee white-rock phosphate.—The two samples of air-dried materials used in this investigation came from deposits which were formerly worked.

Sample 1031. Deposit near Godwin, Maury County.

Sample 1048. Deposit near Tomscreek, Perry County.

Tennessee phosphatic limestone.—Sample 916. Bigby phosphatic limestone from a brown-rock phosphate mine near Mountpleasant, Maury County. Representative of a 100-pound quantity of air-dried material.

Sample 917. Leipers phosphatic limestone from a blue-rock phosphate mine near Gordonsburg, Lewis County. Representative of a 100-pound quantity of air-dried material.

South Carolina land-rock phosphate.—The samples were representative of the commercial material formerly produced from the deposits.

Sample 1138. Lamb's Mine, about 15 miles from Charleston.

Sample 1139. Bulow Mines, Johns Island, Charleston County. Representative of a 150-pound quantity of material.

Idaho, Montana, and Wyoming phosphates.—Samples 454 and 973. Deposit at Conda, Caribou County, Idaho. Commercial kiln-dried materials.

Sample 550. Commercial material from a deposit near Paris, Bear Lake County, Idaho.

Samples 1009, 1010, and 1011. Prospect samples from a deposit near Garrison, Powell County, Mont.

Sample 948. Deposit near Cokeville, Lincoln County, Wyo. Representative of a 200-pound quantity of commercial air-dried material.

Morocco phosphate.—Sample 1162. Commercial material from either the Boujniba or the Kourigha deposits, probably the latter.

Tunisian phosphate.—Sample 552. Commercial material from the Gafsa deposits.

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Christmas Island phosphate.—Sample 452. Commercial material from Christmas Island in the Malay Archipelago.

Connetable Islands phosphate.—Sample 904 was taken from a quantity of material which had lain for many years in the factory yard of a chemical company in New Jersey. The material, which consists principally of hydrated aluminum phosphate, was formerly used in the manufacture of sodium phosphate by alkali treatment processes. The two small Connetable Islands are 13 miles off the coast of French Guiana in approximately latitude 4°54′ north and longitude 51°57′ west.

Curacao Island phosphate.—Sample 943 was taken from a few selected lumps of commercial material, whereas no. 985 was taken from a 200-pound quantity representative of a large commercial shipment from Curacao Island in the Dutch West Indies.

Nauru Island phosphate.—Sample 450. Commercial material from Nauru Island, in the Pacific Ocean in longitude 165°55′ east, 26 miles south of the Equator and about 2,200 miles north by east from Sydney, Australia.

Ocean Island phosphate.—Sample 451. Commercial material from Ocean Island, in the Pacific Ocean 165 miles east of Nauru Island and 52 miles south of the Equator. Geographically, Ocean Island belongs to no particular group of islands, but is assigned to the Gilbert group for administrative purposes.

Fluorapatite.—Sample 905. Selected material from a deposit in Quebec Province, Canada.

Chlorapatite.—Sample 634. Deposit at Kragerö, Norway.

Bone ash.—Sample 971. High-grade commercial material.

METHODS OF CHEMICAL ANALYSIS

Methods for the complete chemical analysis of phosphate rock have not been compiled into a single publication. The methods used in this investigation were selected from the literature, so far as they were available and were known to give accurate results. Published methods for the determination of certain elements in other substances were so modified as to make them applicable to phosphate rock. Since an extended discussion of analytical methods would be out of place here, only such information as is necessary to identify the methods used is given in the following paragraphs.

TOTAL PHOSPHORIC ACID

The sample was brought into solution by the method recommended by Lundell and Hoffman (*104*), and the phosphoric acid was determined by the gravimetric method of the Association of Official Agricultural Chemists (*6, p. 14*). As was recommended by Lundell and Hoffman (*104*), the yellow precipitate of ammonium phosphomolybdate was dissolved in a solution of ammonium hydroxide and ammonium citrate, and the filter paper was washed finally with dilute hydrochloric acid in order to dissolve any iron phosphate that may have been precipitated along with the ammonium phosphomolybdate.

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TOTAL CALCIUM, IRON, AND ALUMINUM

The sample was brought into solution by the method recommended by Lundell and Hoffman (*104*). In determining the calcium it was first precipitated as the sulphate in the presence of alcohol, in order to effect its separation from magnesium, and after reprecipitation as the oxalate it was weighed as the oxide. Total aluminum was determined by the routine method of Lundell and Hoffman (*104*), and the results were corrected for the presence of titanium, chromium, and, when necessary, vanadium. Total iron was determined by reducing with stannous chloride and titrating with potassium dichromate, according to the method of Knop (*94*).

MAGNESIUM, MANGANESE, TITANIUM, SODIUM, POTASSIUM, CHROMIUM, VANADIUM, COPPER, ZINC, AND ARSENIC

These elements were determined by the methods briefly outlined by Hill, Marshall, and Jacob (*73*).

SILICA

Total silica was determined by the Berzelius method as modified by Hoffman and Lundell (*77, p. 805; 79*). Hill and Jacob (*69*) have shown that this method is applicable to the determination of silica in phosphate rock, whereas the method of digestion with hydrochloric acid, ordinarily used in rock analysis, gives low results because of the presence of fluorine in phosphate rock. The ordinary method for determining silica (*69*) was used on the samples of mechanical fractions separated from finely divided phosphates.

CARBON DIOXIDE

Carbon dioxide was determined by the acid evolution method, using Knorr's apparatus.

FLUORINE

Unless stated otherwise, the fluorine determinations were made by the volatilization method outlined by Wagner and Ross (*201*) and modified by Reynolds, Ross, and Jacob (*77, p. 600; 153*). This method accounts for an average of about 93.5 percent of the fluorine present in phosphate rock. The results so obtained have, therefore, been calculated to 100 percent recovery of the fluorine on the basis of an actual recovery of 93.5 percent. The method gives, however, very low and erratic results on materials, such as the Florida waste-pond phosphates, which contain appreciable quantities of silicates decomposable by sulphuric acid (*151*). Fluorine in these materials was determined by the method of Hoffman and Lundell (*79*) as modified by Reynolds and Jacob (*150*). This modification of the Hoffman-Lundell method will hereinafter be referred to as the fusion-acid extraction method.

CHLORINE, IODINE, AND BROMINE

Chlorine was determined gravimetrically according to Hillebrand's method for silicate rocks (*76, p. 220*). Iodine was determined by the furnace method as outlined by McHargue (*109*) and applied by Hill and Jacob (*70*) to the analysis of phosphate rock. Several samples

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were tested for bromine by treating the aqueous layer from the iodine determination with saturated chlorine water, extracting the liberated bromine with carbon tetrachloride, and determining it colorimetrically by comparison with a standard solution.

SULPHUR, ORGANIC MATTER, WATER, AND IGNITION LOSS

The methods used for these determinations have been outlined by Hill, Marshall, and Jacob (*74*).

RESULTS OF CHEMICAL ANALYSES

The principal data obtained on the samples described on pages 14 to 17 are given in tables 3 to 6. Data on the composition of phosphates from certain domestic deposits not included in the present investigation are summarized in table 7.

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TABLE 3.—*Chemical composition of Florida phosphates*

Sample no.	Location of deposit	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_2 [1]	TiO_2	Na_2O	K_2O	MnO	Cr_2O_3	V_2O_3	SiO_2 [2]	CO_2	F [3]	Cl	SO_3 [4]	Total water, organic carbon, and nitrogen [5]	Total: Uncorrected	Total: Corrected [6]
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	LAND-PEBBLE PHOSPHATE																			
618	Pierce	30.53	46.16	0.53	0.89	1.51	0.04	0.46	0.18	0.020	0.000	0.00	9.80	3.69	3.92	0.01	1.34	[7] 2.41	101.49	99.84
617	Brewster	30.70	46.48	.33	.71	2.14	.05	.62	.20	.020	.000	.00	8.52	2.10	4.01	.01	1.32	[7] 4.25	101.46	99.77
619	Nichols	30.98	47.27	.10	.71	1.63	.04	.53	.18	.020	.010	.01	8.11	4.38	3.98	.01	1.13	2.62	101.71	100.03
910	Mulberry	31.09	46.57	.25	1.11	2.59	.072	.57	.14	.042	.013	.02	7.28	3.76	3.94	.01	.98	2.91	101.35	99.69
947	Brewster	31.28	47.20	.20	.97	1.69	.064	.59	.19	.012	.009	<.01	7.59	3.70	4.04	.01	1.14	2.79	101.48	99.78
790	Not known	31.40	47.37	.14	.99	1.62	.06	.41	.45	.025	.012	.01	8.92	3.63	3.97	.03	1.19	[7] 1.12	101.35	99.68
439	Mulberry	33.22	47.68	.21	1.01	1.90	.05	.42	.15	.050	.013	.01	7.66	2.63	3.87	.02	[8] .67	2.13	101.69	100.06
622	Nichols	33.56	48.25	.17	.99	.86	.03	.58	.18	.002	.011	.01	8.39	2.67	3.96	(9)	[8] .84	[7] 1.85	102.35	100.68
627	Lakeland	33.70	47.97	.12	.81	1.56	.03	.60	.25	.005	.000	.00	7.51	1.84	3.90	(9)	.86	[7] 2.22	101.37	99.73
912	Mulberry	35.37	49.05	.08	1.05	.70	.060	.15	.11	.017	.009	.01	7.48	1.48	3.95	.003	.20	1.74	101.46	99.80
898	Lakeland	35.55	49.77	.04	.87	.68	.03	.07	.09	.005	.000	.00	7.38	1.74	3.95	(9)	[8] .42	[7] 1.28	101.88	100.22
	HARD-ROCK PHOSPHATE																			
771	Not known	31.25	42.52	0.21	2.61	1.83	0.06	0.09	0.06	0.020	0.010	0.01	12.95	2.41	3.35	<.005	[8] 0.16	3.94	101.48	100.07
589	Floral City	34.68	49.10	.05	1.38	1.26	.04	.41	.33	.034	.009	.02	6.39	1.82	3.79	.00	[8] .14	[7] 1.46	100.91	99.31
434	Dunnellon	35.33	50.19	.03	1.19	.88	.03	.42	.26	.036	.009	.02	4.32	2.78	3.76	.00	[8] .12	[7] 1.32	100.70	99.12
932	do	35.99	51.08	.05	.52	.69	.039	.10	.06	.014	.004	.01	5.01	2.19	3.91	.008	.01	1.67	101.36	99.71
	SOFT PHOSPHATE																			
1091	Bartow	25.47	30.89	0.34	10.49	3.26	0.17	0.00	0.21	Trace	0.038	0.02	21.46	1.24	[10] 2.23	(9)	0.00	[7] 5.22	101.04	100.10
580	Not known	29.49	16.67	.08	23.05	3.28	.19	.67	.13	.020	.040	.005	13.60	.37	1.23	.12	.00	[7] 11.83	100.78	100.23
728	Juliette	31.80	41.61	.22	5.82	1.54	.11	.26	.14	.014	.018	.00	10.67	1.87	3.33	Trace	[8] .17	4.03	101.60	100.20
443	Gilchrist County	34.94	48.49	.00	2.08	.86	.05	.17	.05	.032	.012	.00	5.23	2.69	3.79	.02	.00	[7] 3.05	101.46	99.86
	WASTE-POND PHOSPHATE																			
727	Dunnellon	21.63	28.70	0.84	13.73	2.57	0.22	0.00	0.53	0.020	0.030	0.01	23.27	1.00	[10] 1.94	(9)	0.00	[7] 5.86	100.35	99.53
726	Felicia	23.48	30.89	.55	11.49	3.91	.36	.20	.47	.022	.028	.02	19.78	1.70	[10] 2.08	.005	[8] .14	6.05	101.18	100.30
915	Dunnellon	23.63	25.20	.21	16.67	4.25	.36	.40	.36	.013	.038	.01	16.80	1.26	[10] 1.84	.01	.00	8.69	99.74	98.97

[1] Total Fe.
[2] Total Si.
[3] Determined by the volatilization method (*153*), except as stated otherwise.
[4] Total sulphates, except as stated otherwise.
[5] Including water derived from combustion of organic matter but exclusive of water driven off at 105° C.
[6] Corrected for O equivalent of F and Cl.
[7] Ignition loss, constant weight at 1000° C., corrected for total CO_2.
[8] Total S.
[9] Not determined.
[10] Determined by the fusion-acid extraction method (*150*).

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TABLE 4.—*Chemical composition of Tennessee phosphates*

Sample no.	Location of deposit	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3[1]	TiO_2	Na_2O	K_2O	MnO	Cr_2O_3	V_2O_3	SiO_2[2]	CO_2	F	Cl	SO_3[3]	S[4]	Total water, organic carbon, and nitrogen[5]	Total: Uncorrected	Total: Corrected[6]
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
BROWN-ROCK PHOSPHATE																					
587	Wales	30.17	41.87	0.16	2.72	3.43	0.16	0.27	0.64	0.23	0.003	0.00	14.38	1.05	3.24	0.01	[7] 0.63	([8])	[9] 1.75	100.71	99.35
[10] 56	Not known	31.28	44.85	.34	3.06	3.30	.08	.32	.62	.24	.007	.00	8.58	1.91	3.56	.07	1.24	0.48	1.93	101.87	100.17
564	Wales	32.85	45.31	.15	2.22	3.34	.08	.28	.42	.20	.005	.00	8.12	1.11	3.62	.01	[7] .77	([8])	[9] 3.65	102.13	100.61
762	Mountpleasant	33.73	47.62	.06	1.78	2.25	.05	.14	.31	.27	.007	.00	7.49	1.71	3.87	.005	.75	.00	1.70	101.74	100.11
906	Wales	34.39	47.61	.10	1.17	3.42	.05	.22	.37	.066	.005	.00	7.11	1.31	3.77	.01	.61	.00	1.39	101.60	100.01
908	Mountpleasant	34.44	49.19	.02	1.16	2.52	.07	.19	.26	.13	.006	.00	5.92	1.96	3.81	.01	.70	.00	1.42	101.81	100.21
BLUE-ROCK PHOSPHATE																					
772	Glover	30.45	44.51	0.30	0.72	3.54	0.05	0.16	0.30	0.020	0.006	0.00	9.06	2.00	3.49	0.007	4.08	1.09	2.23	102.01	100.13
930	Gordonsburg	30.97	45.38	.36	1.22	3.42	.086	.37	.43	.015	.005	<.005	9.13	2.59	3.80	.01	1.27	2.09	1.28	102.43	100.05
[11] 1049	Boma	31.22	43.51	.07	1.19	1.79	.081	.22	.55	<.003	.005	<.005	12.36	.91	3.09	.01	2.00	.81	4.14	101.96	100.36
448	Glover	32.03	46.33	.12	.61	3.30	.05	.13	.04	.025	.005	.005	7.68	1.48	3.67	.01	2.45	.55	[9] 3.60	102.09	100.34
449	Gordonsburg	33.65	48.71	.11	.99	2.35	.06	.21	.06	.024	.007	.007	4.89	2.09	3.95	.02	1.06	1.28	[9] 3.57	103.04	100.90
WHITE-ROCK PHOSPHATE																					
1048	Tomscreek	30.20	42.90	0.06	1.39	1.75	0.075	0.13	0.42	<0.003	<0.005	<0.005	16.82	2.36	3.06	Trace	[7] 0.02	([8])	1.66	100.85	99.56
1031	Godwin	35.80	50.79	.06	1.45	.92	.054	.20	.18	.045	<.005	.01	1.91	3.05	3.80	0.01	[7] .35	([8])	2.82	101.45	99.85
PHOSPHATIC LIMESTONE																					
[12] 916	Mountpleasant	11.22	52.08	0.55	0.39	1.27	0.043	0.28	0.18	0.25	<0.005	<0.005	2.43	28.22	1.12	0.01	1.55	0.39	[9] 0.65	100.64	100.02
[12] 917	Gordonsburg	11.68	49.89	.42	.27	1.95	.038	.28	.21	.10	<.005	<.005	5.53	25.57	1.05	.01	2.27	1.01	[9] .21	100.50	99.68

[1] Total Fe.
[2] Total Si.
[3] Total sulphates, except as stated otherwise.
[4] Acid-insoluble sulphide; considered as pyrite, FeS_2.
[5] Including water derived from combustion of organic matter, but exclusive of water driven off at 105° C.
[6] Corrected for O equivalent of F, Cl, and pyritic S.
[7] Total sulphur.
[8] Not determined.
[9] Ignition loss, constant weight at 1000° C., corrected for total CO_2 and for oxidation of pyritic sulphur, when present.
[10] Bureau of Standards standard sample no. 56.
[11] Kidney phosphate; other blue-rock samples are bedded phosphates.
[12] Bigby formation.
[13] Leipers formation.

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TABLE 5.—*Chemical composition of South Carolina and western phosphates*

Sample no.	Location of deposit	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3[1]	TiO_2	Na_2O	K_2O	MnO	Cr_2O_3	V_2O_3	SiO_2[2]	CO_2	F	Cl	SO_3[3]	S[4]	Total water, organic carbon, and nitrogen[5]	Total: Uncorrected	Total: Corrected[6]
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
SOUTH CAROLINA LAND-ROCK PHOSPHATE																					
1139	Bulow mines, Johns Island, S.C.	26.92	43.19	0.28	0.99	1.56	0.08	1.19	0.23	0.090	0.028	0.00	13.30	5.06	3.58	0.02	1.74	0.19	[7] 3.77	102.22	100.65
1138	Lamb's mine, near Charleston, S.C.	27.85	44.88	.36	1.06	1.49	.07	.97	.27	.030	.028	.00	10.04	5.11	3.77	.02	1.97	.18	3.87	101.97	100.32
IDAHO PHOSPHATE																					
550	Paris, Idaho	32.21	45.27	0.17	1.90	0.97	0.09	0.64	0.46	0.005	0.13	0.15	10.36	1.77	3.43	0.03	1.43	0.00	[7] 1.88	100.90	99.46
454	Conda, Idaho	32.24	45.96	.22	.96	.80	.07	.78	.40	.002	.13	.35	7.50	1.80	3.40	.03	1.66	.00	4.34	100.64	99.21
973	do	32.53	45.99	.31	1.16	.87	.06	.65	.45	.002	.13	.40	8.15	1.72	3.33	.03	1.74	.00	4.35	101.87	100.47
MONTANA PHOSPHATE																					
1011	Garrison, Mont.	27.63	44.65	0.00	0.99	2.16	([8])	0.16	0.22	([8])	([8])	([8])	17.30	0.75	6.98	0.01	0.13	([8])	[7] 1.40	102.38	99.44
1009	do	31.39	43.74	.22	1.91	2.11	0.07	.28	.58	0.042	0.07	0.05	15.29	1.00	3.19	.01	.14	0.01	1.25	101.35	100.01
1010	do	37.47	52.02	.03	.54	.56	.04	.40	.26	.028	.05	.04	4.90	1.18	3.83	.01	.28	.01	.70	102.35	100.74
WYOMING PHOSPHATE																					
948	Cokeville, Wyo.	30.19	46.22	0.08	1.19	0.87	0.10	0.64	0.35	0.004	0.12	0.12	7.19	4.13	3.54	0.03	1.35	0.52	4.30	100.94	99.25

[1] Total Fe.
[2] Total Si.
[3] Total sulphates.
[4] Acid-insoluble sulphide.
[5] Including water derived from combustion of organic matter, but exclusive of water driven off at 105° C.
[6] Corrected for O equivalent of F, Cl, and pyritic S.
[7] Ignition loss, constant weight at 1000° C., corrected for total CO_2 and for oxidation of pyritic sulphur, when present.
[8] Not determined.

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TABLE 6.—*Chemical composition of foreign phosphate rocks, apatites, and bone ash*

Sample no.	Type or source of phosphate	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3 [1]	TiO_2	Na_2O	K_2O	MnO	Cr_2O_3	V_2O_3	SiO_2 [2]	CO_2	F	Cl	SO_3 [3]	Total water, organic carbon, and nitrogen [4]	Total	
																			Uncorrected	Corrected [5]
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1162	Morocco	35.11	53.00	0.16	0.45	0.12	0.025	1.19	0.16	0.0025	0.045	0.00	0.86	4.12	4.24	<0.005	1.40	1.63	102.52	100.74
552	Tunis: Gafsa	27.55	45.93	.45	1.44	.65	.050	1.25	.44	.003	.042	.00	7.76	5.96	3.46	<.005	2.94	3.96	101.89	100.43
452	Christmas Island	39.46	52.50	.10	[6] .80	--------	([7])	.53	.05	([7])	([7])	([7])	.60	2.28	1.32	.02	.00	[8] 2.05	99.71	99.15
943	Curacao Island	40.66	49.50	1.70	[6] .45	--------	([7])	1.23	.04	([7])	([7])	([7])	.50	2.73	.38	.14	.72	[8] 2.46	100.51	100.32
985	do	38.59	49.96	1.23	.40	.61	.024	.88	.09	<.003	<.005	.01	.39	3.90	.70	.16	.61	2.47	100.03	99.70
450	Nauru Island	38.92	54.42	.00	[6] .30	--------	([7])	.45	Trace	([7])	([7])	([7])	.20	2.04	2.62	.01	.00	[9] 2.78	101.74	100.64
451	Ocean Island	40.32	54.08	.00	[6] .20	--------	([7])	.49	Trace	([7])	([7])	([7])	.40	1.06	2.97	.01	.00	[9] 1.88	101.41	100.16
905	Fluorapatite	40.30	52.40	.46	[6] .60	--------	([7])	.00	.00	([7])	([7])	([7])	3.08	1.51	3.26	.16	.00	[9] .44	102.21	100.80
634	Chlorapatite	40.50	52.97	.29	.98	.18	([7])	.22	.10	([7])	([7])	([7])	1.16	.00	.17	4.13	.00	[9] .48	101.18	100.18
971	Bone ash	40.36	54.04	1.07	.00	.24	.015	.96	.09	<.003	<.005	<.005	.45	.70	.054	.03	.40	[10] .63	99.05	99.02
904	Connetable Islands	54.51	.00	.31	36.92	4.43	.16	.07	.06	<.003	.017	.005	1.82	.00	.06	Trace	.10	[11] 2.01	100.48	100.45

[1] Total Fe.
[2] Total Si.
[3] Sulphates only.
[4] Including water derived from combustion of organic matter, but exclusive of water driven off at 105° C.
[5] Corrected for O equivalent of F and Cl.
[6] Al_2O_3 plus Fe_2O_3.
[7] Not determined.
[8] Ignition loss, constant weight at 1100° C., corrected for total CO_2 from carbonate.
[9] Ignition loss, constant weight at 1000° C., corrected for total CO_2 from carbonate.
[10] This sample gave an ignition loss, corrected for total CO_2 from carbonates, of 1.50 percent when heated to constant weight at 1250° C. in a tube furnace in a current of air dried by sulphuric acid.
[11] This sample lost 22.58 percent of water of hydration when heated to constant weight at 105° C.

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TABLE 7.—*Chemical composition of phosphates from domestic deposits not included in the present investigation*

Source and type of phosphate	Literature reference	Samples analyzed	Average composition												
			P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3	Na_2O	K_2O	SiO_2	CO_2	F	SO_3	Insoluble material	Other constituents
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alabama; phosphatic nodules and shell casts from Dallas, Greene, Hale, and Perry Counties	(*192*)	10	19.40	34.99	------	------	------	------	------	------	------	------	------	22.28	------
Alabama; phosphate rock from Elk River Valley, Limestone County	(*165*)	27	26.83	------	------	------	------	------	------	------	------	------	------	------	------
Arkansas; samples from deposits in the northern part of the State	(*12*)	85	26.62	------	------	[1] 8.59	------	------	------	------	------	------	------	------	------
Florida; river pebble from Peace and Caloosahatchee Rivers	(*44*)	2	28.41	44.22	0.61	1.69	0.94	------	------	------	5.13	2.46	------	9.12	------
Florida; mine-run land pebble from Fort Meade, Polk County	(*200*)	1	15.38	22.79	------	[1] 7.50	------	------	------	45.99	1.53	1.58	------	------	------
Florida; mine-run hard rock from Newberry, Alachua County	(*200*)	1	30.69	42.07	------	[1] 5.03	------	------	------	14.37	2.22	3.68	------	------	------
Georgia; lumps, nodules, and pebbles from Decatur, Echols, Glynn, and Thomas Counties	(*106*)	7	32.08	46.97	------	[1] 2.62	------	------	------	------	------	------	------	7.42	------
Kentucky; samples from Clark, Fayette, Franklin, Harrison, Scott, and Woodford Counties	(*49*)	40	29.16	------	------	[1] 5.93	------	------	------	------	------	------	------	------	------
Montana; Melrose, Silver Bow County	(*50*)	2	34.94	51.27	------	1.50	.46	------	------	------	------	------	------	4.06	------
North Carolina; samples from Duplin, Onslow, and Sampson Counties	(*37*)	40	19.00	------	------	------	------	------	------	------	1.82	------	------	43.17	------
Oklahoma; nodules from Cotton County	(*179, 180*)	1	24.90	39.76	Tr.	5.11	3.23	0.43	0.79	16.83	3.07	4.31	Tr.	------	MnO–0.176 TiO_2–.35
Pennsylvania; white and blue rocks and red nodules from Juniata County	(*83*)	------	13.7–24.7	------	------	[1] 5.0–18.0	------	------	------	------	------	------	------	30.0–50.0	------
South Carolina; samples of river rock	(*163*)	8	25.15	------	------	------	------	------	------	------	3.50	------	------	15.87	------
Tennessee; samples from various localities in Johnson County	(*90*)	6	23.87	32.56	1.09	6.71	2.68	[2] 2.40	------	19.20	2.19	1.20	0.23	------	MnO–3.89
Utah; Dunnellon claim, Crawford Mountains	(*119, p. 210*)	1	36.35	50.97	.22	.50	.26	2.00	.47	.30	1.72	.40	2.98	1.82	------
Utah; Elsinore claim, Tunnel Hollow, Morgan County	(*119, p. 210*)	1	32.05	46.80	.26	.90	.33	2.08	.58	------	2.14	.66	2.34	9.40	------
Utah; Woodruff Creek, Rich County	(*92*)	1	32.44	43.02	.83	[1] 1.52	------	------	------	------	.85	1.36	[3] 2.24	------	------
Virginia; phosphate pebbles from Clifton Forge, Alleghany County	(*202, p. 302*)	1	27.62	30.86	.27	1.04	1.21	------	------	------	------	------	------	25.26	------
Virginia; ilmenite nelsonite from Nelson County	(*204, p. 109*)	4	10.01	12.44	.71	------	[4] 8.43	------	------	[5] .97	Tr.	.60	([6])	------	MnO–0.21 TiO_2–39.74
Virginia; rutile nelsonite from Nelson County	(*204, p. 120*)	2	8.78	11.65	.20	------	[7] 3.26	------	------	.81	Tr.	.52	([8])	------	[9] MnO–0.26 TiO_2–67.79
Virginia; apatite separated from ilmenite nelsonite	(*204, p. 108*)	1	41.30	54.37	.53	------	.61	------	------	------	------	2.50	------	.33	Cl–0.10 TiO_2–0.20
Wyoming; Wind River Mountains near Lander, Fremont County	(*34*)	9	21.45	37.91	------	[1] 1.94	------	------	------	------	------	------	------	------	------

[1] Al_2O_3 plus Fe_2O_3.
[2] Na_2O plus K_2O. 3 samples contained an average of 0.45 percent Na_2O and 1.86 percent K_2O.
[3] Also contained 0.92 percent S as FeS_2.
[4] Also contained 26.79 percent FeO.
[5] 3 samples.
[6] 2 samples contained an average of 1.31 percent total S.
[7] Also contained 6.5 percent FeO.
[8] Contained 0.98 percent total S.
[9] 1 sample.

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All figures given in the principal tables of results and nearly all of those in the other tables are the average of duplicate determinations. Unless stated otherwise, all results have been calculated to the moisture-free basis (105° C.). In these tables, the omission of a significant figure indicates that a positive test for the element was not obtained, whereas a faintly positive test is indicated by the inequality sign (<).

PHOSPHORIC ACID

The results of analyses for phosphoric acid (P_2O_5) in the present commercial grades and types of domestic phosphate rock (tables 3–5) range from approximately 30 to 37 percent, roughly equivalent to 65.5 to 81 percent B.P.L.[7] Additional data on the phosphoric acid content of these materials are given in tables 9 to 11.

Four samples of Florida soft phosphate contained 25.47 to 34.94 percent phosphoric acid (table 3). It should be noted, however, that only one of these samples (no. 1091) was taken from commercial material, and that this material is not used for the manufacture of phosphate fertilizers by chemical processes but for direct application to the soil and for other purposes. The samples of Florida waste-pond phosphate contained 15.34 to 25.31 percent phosphoric acid (tables 3 and 9). As sold at the present time, this material usually contains approximately 20 to 24 percent phosphoric acid.

The phosphoric acid content of 10 samples of Tennessee phosphatic limestone ranged from 10.09 to 19.13 percent, the average being12.43 percent (tables 4 and 10). These samples contained 14.86 to 28.91 percent carbon dioxide with an average of 25.31 percent, those highest in phosphoric acid containing the smallest quantities of carbon dioxide.

The phosphoric acid in 13 prospect samples from the Garrison, Mont., deposits ranged from 27.63 to 37.47 percent (tables 5 and 11), whereas a sample of commercial material (no. 1252, table 11) contained 36.38 percent phosphoric acid. Five samples of commercial material from a deposit at Cokeville, Wyo., contained 26.60 to 30.19 percent phosphoric acid (tables 5 and 11). The phosphate from this deposit is sold principally for direct application to the soil.

The results, 26.92 and 27.85 percent phosphoric acid, obtained on two samples of South Carolina land-rock phosphate (table 5) fall within the range, 25 to 28 percent phosphoric acid, reported by Shepard (*182*) on several hundred samples of commercial material mined in the early days of the industry.

Figures on the phosphoric acid content of a few samples of Arkansas, Kentucky, Oklahoma, and South Carolina phosphates are given in table 12.

The results given in tables 6 and 13 show that the north-African phosphates, with the exception of those from Morocco, contain, in general, much less phosphoric acid than do the usual grades of commercial rock produced in the United States. In this respect they are comparable with the phosphate formerly mined in South Carolina. Morocco phosphate, on the other hand, usually contains about 34 to 35 percent phosphoric acid, and is comparable, in this respect, with Florida hard rock and the higher grades of Florida land pebble and Tennessee brown rock.

[7] Bone phosphate of lime, an expression used in the phosphate-rock industry, to designate the phosphoric acid content of natural phosphates in terms of tricalcium phosphate, $Ca_3(PO_4)_2$.

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The highest grade commercial phosphate rocks analyzed in this investigation were those from Angaur, Christmas, Curacao, Makatea, Nauru, and Ocean Islands, which contained 37.89 to 40.87 percent phosphoric acid, roughly equivalent to 82.5 to 89.0 percent B.P.L. (tables 6 and 14).

CALCIUM AND MAGNESIUM

Calcium is the predominating basic element in all the principal commercial types and grades of phosphate rock produced throughout the world. Although the calcium occurs principally in combination with the phosphate radical, it also occurs in combination with fluorine and the carbonate and sulphate radicals.

Excluding the Florida soft and waste-pond phosphates and the Tennessee phosphatic limestones, the results given in tables 3 to 5 indicate that the calcium oxide in the domestic types of phosphates ranges from about 42 to 52 percent in rock containing 27.0 to 37.5 percent phosphoric acid. Although the calcium content of a particular type of rock usually tends to increase with increase in the phosphoric acid content, the increase is not always in direct proportion to the increase in phosphoric acid, principally because of variations in the amounts of carbonate and sulphate. In proportion to the phosphoric acid, South Carolina land-rock phosphate contains more calcium than do the other domestic types of phosphate. The Wyoming rock and the lower grades of Florida land pebble come next in this respect, but the other domestic types and the higher grades of land pebble do not show consistent or marked differences.

As reported in the literature (*32, p. 533; 44; 58, p. 30; 90; 92; 99; 119, p. 210; 122; 126; 127; 134; 144; 158; 163; 168, p. 63; 179; 180*), the magnesium in domestic phosphate rock ranges from traces to about 2 percent magnesium oxide, the majority of the samples containing more than 0.3 percent. As a whole, the reported figures are much higher than those obtained in this investigation (tables 3–5). With the exception of one sample of Florida waste-pond phosphate (no. 727, table 3), none of the domestic materials showed more than 0.55 percent magnesium oxide, and the majority of the samples contained less than 0.20 percent. Although the results do not indicate any regularity in the magnesium content of a particular type of phosphate, with the possible exception of South Carolina land rock, the samples of Florida waste-pond and soft phosphates, Tennessee phosphatic limestone, and South Carolina rock average higher in magnesium than the other domestic types. Of the foreign and miscellaneous phosphates (table 6), Curacao Island rock and bone ash are the only samples containing more than 1 percent magnesium oxide. In general, the magnesium content of a particular type of rock tends to decrease as the phosphoric acid content increases.

ALUMINUM, IRON, AND TITANIUM

The results given in tables 3 to 5 show that, among the commercial domestic types of phosphate rock, the Tennessee brown and blue rocks, are generally characterized by comparatively high percentages of aluminum and iron, particularly the latter. In the blue-rock phosphates a large portion of the iron is usually present in the form of pyrite (FeS_2), whereas the brown-rock phosphates usually contain comparatively little or no pyrite. The other commercial domestic types of phosphate rock do not show striking differences in their per-

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centages of aluminum and iron. The Florida soft and waste-pond phosphates, particularly the latter, contain, in general, very high percentages of aluminum. Although much of the aluminum in these phosphates is doubtless derived from extraneous materials such as soil clays, it is known that some samples contain significant quantities of aluminum phosphate (p. 75). As shown in table 6, the Morocco and the Christmas, Curacao, Nauru, and Ocean Islands phosphates are very low in aluminum and iron.

Titanium was found in all samples of domestic phosphates (tables 3–5), but, except in the Florida soft and waste-pond phosphates, the amount did not exceed 0.10 percent titanium dioxide (TiO_2). The results (0.03 to 0.06 percent TiO_2) on Florida hard-rock phosphate are considerably lower than those (0.13 to 0.86 percent TiO_2) previously reported (*32, p. 533; 122*) for this type of material. Gray (*58, p. 30*) reported a range of 0.02 to 0.30 percent titanium dioxide in five samples of Florida land pebble, whereas the results here given on 11 samples show a range of only 0.03 to 0.07 percent. Mansfield (*119, p. 210*) stated that titanium was not found in four samples of Idaho, Utah, and Wyoming phosphates. The figures given in table 5 indicate, however, that the western phosphates commonly contain small quantities of this element. The amount of titanium in a particular type of phosphate usually decreases with increase in the phosphoric acid.

SODIUM AND POTASSIUM

Data on the alkali content of domestic phosphate rock are reported by Clarke (*32, p. 533–534*), Gray (*58, p. 30*), Jenkins (*90*), Larison (*99*), Mansfield (*119, p. 210*), Matson (*122*), Pike (*144*), Ross and Merz (*168, p. 63*), and Shead (*179, 180*). The reported results range from traces in Florida hard-rock phosphate to about 2.5 percent sodium and potassium oxides in Utah rock and about 4 percent in rock from Johnson County, Tenn.

With the exception of the Idaho and South Carolina rocks, which contained 1.10 to 1.42 percent of Na_2O and K_2O, none of the domestic phosphates analyzed in this investigation contained more than 1 percent total alkali. The results indicate, in general, that the Florida waste-pond, Montana, and Tennessee phosphates, particularly Tennessee brown rock, contain higher percentages of potassium than of sodium, whereas the other types of phosphate, particularly Florida land pebble, South Carolina land rock, bone ash, and the foreign phosphates, usually contain more sodium than potassium. With a particular type of phosphate, the total alkali content tends, as a general rule, to decrease as the phosphoric acid content of the rock increases.

MANGANESE, CHROMIUM, AND VANADIUM

The possible occurrence of manganese in natural phosphates is of particular interest to the fertilizer industry because of the beneficial effect of this element on the growth of plants in certain soils (*171*).

Matson (*122*) reported 0.08 percent manganese oxide (MnO) in a sample of phosphatic limestone from Christina, Fla., and Gray (*58, p. 30*) reported 0.01 to 0.35 percent in six samples of the various commercial grades of Florida land pebble. Shead (*179, 180*) found 0.176 percent manganese oxide in a sample of low-grade phosphate from Cotton County, Okla. According to Jenkins (*90*), six samples of low-

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grade phosphate from deposits in Johnson County, Tenn., contained 0.46 to 17.53 percent manganese oxide. Murray and Renard (*128, p. 452–495*) have shown that fossil bones and phosphatic concretions from deep-sea deposits frequently contain comparatively large percentages of manganese.

With the exception of Tennessee brown-rock phosphate and phosphatic limestone, the materials analyzed during this investigation (tables 3–6) contained not more than 0.10 percent and usually less than 0.05 percent manganese oxide. Manganese was present, however, in all samples. The Tennessee brown rocks contained 0.066 to 0.27 percent and the phosphatic limestones 0.10 to 0.25 percent manganese oxide. The samples of African and island phosphates and bone ash were very low in manganese. The results indicate that the manganese in a particular type of phosphate tends to decrease with increase in the phosphoric acid content.

According to Mansfield (*119, p. 211*), F. K. Cameron was the first to suggest that the green color of solutions obtained by treating western phosphate rock with sulphuric acid might be due to the presence of chromium. This was confirmed in the United States Geological Survey by the analysis of several composite samples of rocks from Idaho, Utah, and Wyoming, which were found to contain 0.08 to 0.14 percent chromium trioxide (Cr_2O_3). The Geological Survey's chemists found 0.11 to 0.23 percent chromium trioxide in individual samples of high-grade phosphate from various deposits in Idaho. Larison (*99*) and Ross and Merz (*168, p. 63*) also reported 0.07 percent chromium trioxide in two samples of Idaho phosphate. Grammont (*56*) found 0.013 percent chromium trioxide in a sample of Florida pebble and 0.016 to 0.041 percent in six samples of north-African phosphate.

All samples of Tennessee phosphates analyzed in this investigation contained chromium in amounts ranging from <0.005 to 0.007 percent chromium trioxide (table 4). The chromium trioxide in the samples of western phosphates ranged from 0.05 to 0.13 percent (table 5), and in the Florida phosphates from 0.004 to 0.040 percent (table 3), excluding four samples of land pebble which contained no chromium.

According to Mansfield (*119, p. 212*), the presence of vanadium in western phosphates was recognized as early as 1911 by chemists in the Geological Survey. Analyses made later in the Survey laboratory showed 0.09 percent vanadium trioxide (V_2O_3)[8] in a composite sample of high-grade rocks from different parts of the Idaho field. The Survey's chemists found 0.33 to 0.43 percent vanadium trioxide in three samples of phosphate from Montpelier Canyon, Idaho, and 0.19 and 0.23 percent in two samples from the Paris Canyon district. The presence of vanadium in Idaho phosphate has been noted also by Larison (*99*) and by Ross and Merz (*168, p. 63*). Other instances of the occurrence of vanadium in phosphate rock have not come to the authors' attention.

Hess (*68, p. 580*) has pointed out the possibility of the commercial recovery of vanadium from Idaho phosphates in connection with the manufacture of phosphoric acid and phosphatic fertilizers.

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[8] Mansfield reported the vanadium content in terms of vanadium pentoxide (V_2O_5). Owing, however, to the lack of information on the nature of the vanadium compounds in phosphate rock, and in view of certain facts pointed out by Hillebrand (*76, p. 184*), it seems best to report the vanadium as the trioxide instead of the pentoxide.

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As shown in table 5, all samples of western phosphates analyzed in this investigation contained vanadium in amounts ranging from 0.04 percent vanadium trioxide in Montana rock to 0.40 percent in Idaho rock, a sample from Cokeville, Wyo., containing 0.12 percent. Vanadium was not found in Tennessee brown-rock and South Carolina land-rock phosphates (tables 4 and 5). None of the samples of Tennessee blue and white rocks and phosphatic limestones contained more than 0.01 percent vanadium trioxide. With the exception of four samples of land-pebble and two of soft phosphate which contained no vanadium, the Florida phosphates contained vanadium trioxide in amounts ranging from 0.005 to 0.02 percent (table 3).

Comparing the occurrence of manganese, chromium, and vanadium in phosphate rock with their occurrence in other rocks, minerals, and soils is interesting. Clarke states that the weighted average content of manganese oxide in igneous rocks and limestones is 0.118 percent (*32, p. 34*) and that the chromium trioxide in 256 samples of igneous rocks averaged 0.05 percent (*32, p. 712*). Hillebrand (*75*) found as much as 0.03 to 0.05 percent of vanadium trioxide in some varieties of igneous rocks, particularly those poorest in silica, and he also reported that composites of a large number of samples of sandstones and building limestones contained 0.003 and 0.004 percent, respectively. Robinson and Holmes (*162*) reported 0.001 to 0.641 percent of manganese oxide in 34 samples of soil from various localities in the United States, the majority of the samples containing 0.05 to 0.15 percent. Robinson (*160*) found traces to 0.025 percent of chromium trioxide and 0.01 to 0.08 percent of vanadium, reported as the pentoxide, in 26 samples of soil from widely distributed localities in the United States.

On the basis of the data presented in this publication, it seems that, except possibly in the Tennessee phosphatic limestone and brown-rock phosphate, manganese has not concentrated in the domestic phosphate deposits. Mansfield (*119, p. 212*) has pointed out that the chromium content of the western phosphates is usually much greater than the average for igneous rocks, and that a concentration of this element has, therefore, occurred under special conditions. This is not the case, however, with the other domestic types of phosphate. Vanadium, like chromium, has concentrated in the western phosphates, particularly the Idaho rock, but not in the other domestic varieties.

COPPER, ZINC, AND ARSENIC

Grammont (*57*) reported 0.00036 to 0.0023 percent copper oxide (CuO) in six samples of phosphate rock from north Africa, and 0.00125 percent in one sample of Florida pebble. As shown in table 8, all the samples contained copper in amounts ranging from <0.0005 to 0.011 percent copper oxide. Only three samples (Connetable Islands, Idaho, and Wyoming phosphates) contained more than 0.005 percent copper oxide, whereas the majority contained 0.001 to 0.003 percent. In order to avoid possible contamination from bronze and brass sieves, cloth sieves were used in preparing the samples for the copper and zinc determinations.

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TABLE 8.—*Occurrence of copper, zinc, and arsenic in natural phosphates*

Sample no.	Type or source of phosphate	P_2O_5	CuO	ZnO	As_2O_3
		Percent	*Percent*	*Percent*	*Percent*
910	Florida land pebble	31.09	0.003	<0.0005	0.0028
947	do	31.28	.002	<.0005	.0048
790	do	31.40	.001	<.0005	(1)
912	do	35.37	<.0005	<.0005	.0014
771	Florida hard rock	31.25	.001	<.0005	.0004
932	do	35.99	.002	<.0005	.0012
915	Florida waste pond	23.63	<.0005	.005	.0007
580	Florida soft	29.49	.001	.012	(1)
728	do	31.80	.003	.006	.0008
[2] 56	Tennessee brown rock	31.28	.003	<.0005	.0022
762	do	33.73	.002	<.0005	(1)
906	do	34.39	.003	<.0005	.0032
908	do	34.44	.002	.001	.0038
772	Tennessee blue rock	30.45	.004	<.0005	.0023
930	do	30.97	.001	.0005	.0012
[3] 1049	do	31.22	.003	.0005	(1)
1031	Tennessee white rock	35.80	.003	<.0005	(1)
917	Tennessee phosphatic limestone	11.68	.002	<.0005	(1)
973	Idaho	32.53	.011	.001	.0026
1011	Montana	27.63	(1)	(1)	.0088
1009	do	31.39	.003	.025	.0140
1010	do	37.47	(1)	(1)	.0024
948	Wyoming	30.19	.010	<.0005	.0012
1138	South Carolina land rock	27.85	.005	.0005	.0017
985	Curacao Island	38.59	.005	.045	(1)
904	Connetable Islands	54.51	.008	.031	(1)
971	Bone ash	40.36	.004	.017	≦.0001

[1] Not determined. [2] Bureau of Standards standard sample no. 56. [3] Kidney phosphate.

The only published figures on the occurrence of zinc in phosphate rock that have come to the attention of the authors are those of Grammont (*57*), who reported 0.015 to 0.034 percent zinc oxide (ZnO) in six samples of north-African phosphates, and 0.006 percent in one sample of Florida pebble.

As shown in table 8, all samples analyzed in this investigation contained zinc in quantities ranging from <0.0005 to 0.045 percent zinc oxide, the greatest amount being present in Curacao Island phosphate. With the exception of one sample each of Florida soft and Montana phosphates, none of the domestic materials contained more than 0.01 percent zinc oxide, and the majority contained less than 0.001 percent.

Mansfield (*119, p. 212*) states that no arsenic was found in a sample of phosphate from Driggs, Idaho. So far as known to the authors, the literature contains no other references to arsenic in domestic phosphates. The results given in table 8 indicate, however, that arsenic commonly occurs in these materials.[9] With the exception of bone ash which contained not more than 0.0001 percent, the samples showed 0.0004 to 0.0140 percent arsenic trioxide (As_2O_3), the largest amounts being found in two samples from Montana. With the exception of the Montana phosphates, none of the samples contained more than 0.005 percent arsenic trioxide and the majority contained less than 0.0025 percent.

Clarke (*32, p. 642*) reported that composites of numerous samples of igneous rocks, oceanic clays, river silts, and marine muds contained 0.01167, 0.0200, 0.0043, and 0.0160 percent copper oxide and 0.00638, 0.0052, 0.0010, and 0.0070 percent zinc oxide, respectively. These

[9] The arsenic determinations were made by members of the Insecticide Division, Bureau of Chemistry and Soils.

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materials also contained an average of 0.0005 percent arsenic trioxide. Robinson (*160*) reported the presence of copper in eight samples of soils from various parts of the United States, and McHargue (*108*) found 0.0090 percent copper oxide, 0.0034 percent zinc oxide, and 0.00142 percent arsenic trioxide in a sample of virgin Kentucky soil. Headden (*63*) found 0.00033 to 0.00066 percent arsenic trioxide in virgin Colorado soils, whereas the marls underlying these soils contained 0.00053 to 0.00198 percent. As determined by Zuccàri (*211*), 20 samples of soils, taken from different depths in different geological formations, contained 0.00025 to 0.0079 percent arsenic trioxide. A comparison of these results with those obtained on phosphate rock indicates that copper and zinc do not usually tend to concentrate in phosphate deposits. On the other hand, it seems that domestic phosphate rock usually contains somewhat more arsenic than is present in igneous rocks and virgin soils.

BARIUM, RARE EARTHS, AND OTHER METALLIC ELEMENTS

A few samples of phosphate rock were analyzed for barium by the method described by Hillebrand (*76, p. 170*). Barium was not found in a sample of Florida hard-rock phosphate (no. 932), whereas four samples of Florida land pebble (nos. 439, 617, 618, and 619) and two samples of South Carolina land rock (nos. 1138 and 1139) contained traces. The amounts of barium oxide found in other types of domestic phosphates were as follows: Tennessee brown rock (nos. 906 and 908), 0.03 and 0.01 percent, respectively; Tennessee blue rock (no. 930), 0.05 percent; Conda, Idaho, rock, 0.07 percent; and colloidal materials extracted from Florida soft and waste-pond phosphates (nos. 728 and 727), 0.02 and 0.03 percent, respectively.

Several samples were examined for molybdenum by treating their acid solutions with hydrogen sulphide in pressure bottles. The precipitates were ignited gently and tested for molybdenum colorimetrically with stannous chloride and potassium thiocyanate (*77, p. 256*). Negative results were obtained on samples of Florida land-pebble, Tennessee blue-rock, and Idaho phosphates. No tests were made on the other types of rock.

Samples of colloidal material extracted from Florida soft and waste-pond phosphates (nos. 728 and 727) and from Tennessee brown rock (no. 762) were analyzed for zirconium, by the method described by Hillebrand (*76, p. 170*), with negative results. On the other hand, these materials contained 0.01, 0.03, and 0.03 percent, respectively, of rare earths other than zirconium. The rare-earth metals are frequently present in apatites. Starynkevich-Borneman (*187*) reported that 23 samples of apatite from 14 localities in Asia, Europe, and North America contained up to 3.18 percent of rare-earth metal oxides, one sample from the Khibin Mountains, Russia, containing Ce_2O_3, 1.33; La_2O_3, 1.16; Yt_2O_3, 0.05; and Di_2O_3, 0.05 percent. Rare earths were also present in five samples of Russian phosphate rock in amounts ranging from traces to 0.3 percent. Tanakadate and Carobbi (*193*) found cerium, lanthanum, and yttrium in Chinese apatite.

Grammont (*57*) reported the presence of 0.00019 to 0.00076 percent of nickel in six samples of north-African phosphates, and 0.00060 percent in one sample of Florida pebble. Martini (*121*) found nickel in the leg bones of an ox and also in a specimen of human bone. He stated that nickel is apparently a normal constituent of bones. Tanak-

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adate and Carobbi (*193*) found traces of strontium and 0.03 percent of lead oxide (PbO) in a sample of Chinese apatite. The occurrence of a very small quantity of tourmaline in Florida land-pebble phosphate no. 912 (p. 76) indicates the presence of boron. Determinations of these elements were not made in this investigation.

SILICA AND CARBON DIOXIDE

As shown in tables 3 to 5, the silica content of the commercial grades of the various types of phosphate rock produced in the United States ranges from about 4.5 to 10.0 percent, the higher grades of rock containing, in general, the smaller quantities of silica. Results on the commercial phosphate rocks indicate that the different types of rock are not characterized by their silica content. Florida hard-rock phosphate, however, contains, in general, somewhat less silica than do the same grades of Florida land pebble and Tennessee brown rock. As would be expected, the Florida soft and waste-pond phosphates usually contain comparatively large quantities of silica. This is particularly true of the waste-pond phosphates, three samples of which contained 16.80 to 23.27 percent silica (table 3). As shown in table 6, the Morocco and the island phosphates contain comparatively little silica, the figures ranging from 0.20 to 0.86 percent.

All samples of phosphate rock analyzed in this investigation contained carbon dioxide in amounts ranging from 0.37 percent in a sample of Florida soft phosphate (no. 580, table 3) to 5.96 percent in Tunisian phosphate (no. 552, table 6). The figures given in table 3 show, in general, that the carbon dioxide content of Florida land-pebble phosphate tends to decrease with increase in the phosphoric acid content. This tendency does not hold, however, with the other types of domestic phosphate. Of the principal types of domestic phosphate produced at present, Florida land pebble averages the highest in carbon dioxide, followed in order by Florida hard rock, Tennessee blue rock, Idaho rock, Tennessee brown rock, and Montana rock.

FLUORINE

In this investigation special attention has been given to the occurrence of fluorine not only in the domestic types and grades of phosphate rock but also in phosphates from all the important deposits throughout the world, some 200 samples having been analyzed.

Comparatively little information on the fluorine content of natural phosphates is recorded in the literature before the publication in 1928 of a paper by Jacob and Reynolds (*88*). About 25 years before the appearance of this paper, Carnot (*18*, *19*, *20*, *21*, *22*, *23*, *24*, *25*, *26*) published an important series of papers on the occurrence of fluorine in phosphate rock, phosphate minerals, and modern and fossil bones. Carnot's work on phosphate rock was, however, confined principally to the phosphates of Europe and north Africa. Although it has been recognized for many years that fluorine is present in all domestic phosphate rocks that have been used for commercial purposes, the few figures that have been published show very wide variations in the percentages of fluorine in the different types of rock and in the different grades of a particular type.

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DOMESTIC PHOSPHATE ROCK

Excluding those on sample no. 442, which is run-of-mine material, the results given in table 9 show a range of 3.35 to 4.08 percent in the fluorine content of 37 samples of Florida land-pebble and hard-rock phosphates. These figures are, as a rule, much higher than those (1.86 to 3.68 percent fluorine) reported by Carnot (*26*), Eldridge (*44*), Gray (*58, p. 30*), and Parrish and Ogilvie (*136, p. 30*). The low figures on these and other types of domestic phosphate reported in the literature are due, no doubt, to the use of inaccurate analytical methods.

TABLE 9.—*Fluorine content of Florida phosphates*

LAND-PEBBLE PHOSPHATE

Sample no.	Location of deposit	P_2O_5	F[1]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
[2] 442	Mulberry	32.05	3.19	0.100
567	do	30.52	3.86	.126
618	Pierce	30.53	3.92	.128
[3] 617	Brewster	30.70	4.01	.131
619	Nichols	30.98	3.98	.128
910	Mulberry	31.09	3.94	.127
[3] 615	Brewster	31.25	3.96	.127
947	do	31.28	4.04	.129
[3] 616	do	31.35	4.08	.130
790	Not known	31.40	3.97	.126
[3] 436	Mulberry	31.42	3.91	.124
1040	Not known	32.06	3.82	.119
[3] 437	Mulberry	32.21	3.94	.122
[3] 628	Bartow	32.31	3.97	.123
620	Nichols	32.32	3.92	.121
568	Mulberry	32.63	3.97	.122
[3] 438	do	33.18	3.90	.118
[3] 439	do	33.22	3.87	.116
621	Nichols	33.27	3.96	.119
622	do	33.56	3.96	.118
627	Lakeland	33.70	3.90	.116
[3] 1243	Pierce	34.27	4.02	.117
[3] 440	Mulberry	34.64	3.88	.112
912	do	35.37	3.95	.112
570	do	35.50	3.95	.111
898	Lakeland	35.55	3.95	.111
[3] 441	Mulberry	35.63	3.93	.110
569	do	35.96	3.92	.109
	Average	32.78	3.91	.119

HARD-ROCK PHOSPHATE[4]

771	Not known	31.25	3.35	0.107
[3] 590	Benotis	33.52	3.48	.104
[3] 591	Inverness	33.52	3.77	.112
[3] 589	Floral City	34.68	3.79	.109
434	Dunnellon	35.33	3.76	.106
[3] 588	Floral City	35.70	3.86	.108
[3] 623	Hernando	35.74	3.93	.110
[3] 625	Dunnellon	35.75	3.95	.110
[3] 624	do	35.86	3.85	.107
932	do	35.99	3.91	.109
	Average	34.73	3.76	.108

[1] Soft and waste-pond phosphates, except nos. 580, 723, and 443, were analyzed by the fusion-acid extraction method (*150*); other samples were analyzed by the volatilization method (*153*).
[2] Exceptionally high-grade run-of-mine material; other samples of land pebble are commercial washed and screened materials.
[3] Sample representing large shipment.
[4] All samples, except no. 771, the history of which is not known, are commercial washed and screened materials.

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TABLE 9.—*Fluorine content of Florida phosphates*—Continued

SOFT PHOSPHATE

Sample no.	Location of deposit	P_2O_5	F	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
1091	Bartow	25.47	2.23	0.0876
580	Not known	29.49	1.23	.0417
728	Juliette	31.80	3.33	.1047
443	Gilchrist County	34.94	3.79	.1085
	Average	30.43	2.65	.0871

WASTE-POND PHOSPHATE

826	Dunnellon	15.34	0.38	0.0248
581	Not known	18.18	1.53	.0842
828	Felicia	19.83	1.99	.1004
727	Dunnellon	21.63	1.94	.0897
827	do	22.29	2.26	.1014
726	Felicia	23.48	2.08	.0886
825	Dunnellon	23.48	1.81	.0771
[5] 915	do	23.63	1.84	.0779
824	do	24.24	1.93	.0796
725	Juliette	25.31	2.24	.0885
	Average	21.74	1.80	.0828

[5] Commercial material.

In comparison with the other domestic types of phosphate, the fluorine content of commercial land-pebble phosphate is very constant, and the fluorine-phosphoric acid ratios in this material tend, in general, to decrease inversely with phosphoric acid content. This is one of the distinguishing characteristics of Florida land pebble, since with the other domestic phosphate rocks the fluorine-phosphoric acid ratios in the different grades of a particular type usually show very slight variation.

There is considerable variation in the fluorine content of different samples of Florida soft and waste-pond phosphates (table 9). In proportion to their phosphoric acid content, these materials usually contain less fluorine than do the other types of domestic phosphate, and the fluorine-phosphoric acid ratios vary over a considerable range. The very low ratios in some samples, notably nos. 580 and 826, seem to be due to the presence of aluminum phosphate containing comparatively little or no fluorine (p. 75).

As shown in table 10, the fluorine content of Tennessee brown- and blue-rock phosphates and phosphatic limestone tends to vary directly with the phosphoric acid content. The different grades of the bedded variety of blue rock usually contain somewhat higher percentages of fluorine than do the same grades of brown rock. The results obtained on one sample (no. 1049) indicate that the kidney variety of blue rock runs lower in fluorine than does the bedded variety. Analyses of additional samples may show, however, that this is not generally true. The fluorine-phosphoric acid ratios in phosphatic limestone are approximately the same as those in brown-rock phosphate.

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TABLE 10.—*Fluorine content of Tennessee phosphates*

BROWN-ROCK PHOSPHATE

Sample no.	Location of deposit	P_2O_5	F [2]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
[3] 585	Mountpleasant	25.74	2.80	0.109
[4] 573	do	29.40	3.22	.110
[4] 575	do	29.90	3.32	.111
587	Wales	30.17	3.24	.107
[5] 56	Not known	31.28	3.56	.114
[4] 577	Mountpleasant	31.57	3.48	.110
[4] 578	do	32.37	3.60	.111
[4] 574	do	32.80	3.49	.106
564	Wales	32.85	3.62	.110
566	Mountpleasant	33.30	3.72	.112
586	do	33.52	3.89	.116
762	do	33.73	3.87	.115
584	do	34.18	3.78	.111
906	Wales	34.39	3.77	.110
908	Mountpleasant	34.44	3.81	.111
565	do	34.80	3.94	.113
774	Wales	35.01	4.02	.115
[6] 583	Mountpleasant	37.51	4.08	.109
	Average	32.61	3.62	.111

BLUE-ROCK PHOSPHATE [1]

[4] 571	Gordonsburg	27.90	3.29	0.118
[4] 572	do	29.16	3.37	.116
772	Glover	30.45	3.49	.115
930	Gordonsburg	30.97	3.80	.123
[4] 576	do	31.22	3.71	.119
[7] 1049	Boma	31.22	3.09	.099
448	Gordonsburg	32.03	3.67	.115
449	do	33.65	3.95	.117
	Average	30.83	3.55	.115

WHITE-ROCK PHOSPHATE

[8] 1048	Tomscreek	30.20	3.06	0.101
[8] 1031	Godwin	35.80	3.80	.106
	Average	33.00	3.43	.104

PHOSPHATIC LIMESTONE

775	Unknown	10.09	1.24	0.123
446	Gordonsburg	10.16	1.03	.101
579	Mountpleasant	10.53	1.20	.114
445	Wales	10.61	1.13	.107
916	Mountpleasant	11.22	1.12	.100
444	do	11.38	1.57	.138
917	Gordonsburg	11.68	1.05	.090
447	Mountpleasant	14.04	1.56	.111
791	Unknown	15.45	1.68	.109
770	do	19.13	2.28	.119
	Average	12.43	1.39	.111

[1] Unless stated otherwise, all samples are from commercial materials.
[2] Determined by the volatilization method (*153*).
[3] Run-of-mine material.
[4] Sample representing large shipment.
[5] Bureau of Standards standard sample no. 56.
[6] Selected sample of exceptionally high-grade material.
[7] Selected sample of kidney phosphate; other blue-rock samples are bedded phosphates.
[8] Selected sample.

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The figures for fluorine (2.91 to 6.98 percent) in western phosphates given in table 11 are very much higher than those (0.40 to 1.10 percent) reported by Gale and Richards (*51*) and Larison (*99*). It will be noted that two samples (nos. 1011 and 1012) of the Montana phosphates were exceptionally high in fluorine, containing 6.98 and 4.60 per cent, respectively. Of all the samples of domestic phosphates examined during this investigation, these were the only ones in which the presence of crystalline calcium fluoride (fluorite) was revealed by microscopical examination. The local occurrence of fluorite as coatings, seams, or specks in western phosphate rock had been noted previously by Mansfield and Girty (*119, p. 213*) and Gale and Richards (*51*).

TABLE 11.—*Fluorine content of phosphate rocks from Western United States*

Sample no.	Location of deposit	P_2O_5	F [2]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
	IDAHO PHOSPHATE [1]			
492	Montpelier	30.15	3.34	0.111
493	do	31.08	3.39	.109
489	Georgetown	31.97	3.49	.109
773	Conda	31.97	3.36	.105
1253	do	32.13	3.80	.118
550	Paris	32.21	3.43	.106
454	Conda	32.24	3.40	.105
973	do	32.53	3.33	.102
490	Paris	34.40	3.76	.109
494	Georgetown	34.96	3.70	.106
	Average	32.36	3.50	.108
	MONTANA PHOSPHATE [3]			
1011	Garrison	27.63	6.98	0.253
1013	do	28.85	2.91	.101
1018	do	29.81	2.99	.100
1016	do	30.27	3.05	.101
1009	do	31.39	3.19	.102
1019	do	31.47	3.66	.116
1020	do	32.24	3.39	.105
1007	do	32.54	3.54	.109
1017	do	34.92	3.80	.109
1014	do	35.12	3.80	.108
1012	do	36.07	4.60	.128
1252	do	36.38	4.03	.111
1008	do	36.96	4.05	.110
1010	do	37.47	3.83	.102
	Average [4]	33.12	3.52	.106
	WYOMING PHOSPHATE [1]			
[5] 467	Cokeville	26.60	3.10	0.117
[5] 491	do	28.84	3.39	.118
[5] 469	do	29.75	3.51	.118
468	do	29.79	3.44	.115
948	do	30.19	3.54	.117
	Average	29.03	3.40	.117

[1] Samples of commercial materials.
[2] Determined by the volatilization method (*153*).
[3] Prospect samples, except no. 1252 which was from commercial material.
[4] Excluding nos. 1011 and 1012.
[5] Sample representing large shipment.

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The results given in table 12 indicate that, in proportion to their phosphoric acid content, the Oklahoma and South Carolina phosphates generally contain significantly larger quantities of fluorine than do any of the other types of domestic phosphate rock analyzed in this investigation, except the two samples of Montana phosphate discussed in the preceding paragraph. The amounts of fluorine (2.21 to 3.16 percent) found by the authors in three samples of Kentucky brown-rock phosphate are very much higher than those (1.02 to 1.38 percent) reported by Phalen (*139*) in comparable grades of this material. On the other hand, Shead (*179*, *180*) reported 4.31 percent fluorine in a sample of phosphate from Cotton County, Okla., whereas the authors found 3.32 percent fluorine in a sample from the same locality.

TABLE 12.—*Fluorine content of Arkansas, Kentucky, Oklahoma, and South Carolina phosphates*

Sample no.	Location of deposit	P_2O_5	F [1]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
[2] 1267	Arkansas; Independence County	31.98	3.71	0.116
[3] 1235	Kentucky; Wallace [4]	21.19	2.21	.104
[3] 1245	do	23.68	2.56	.108
[3] 1234	do	27.80	3.16	.114
[3] 1242	Oklahoma; Cotton County	24.31	3.32	.137
[6] 495	South Carolina land rock	16.07	2.20	.137
[7] 1139	do.[5]	26.92	3.58	.133
[7] 1138	do.[8]	27.85	3.77	.135
[6] 650	do	28.86	3.43	.119

[1] The Kentucky phosphates nos. 1235 and 1245 were analyzed by the fusion-acid extraction method (*150*); the other samples were analyzed by the volatilization method (*153*).
[2] Selected material.
[3] Sample from an abandoned mine.
[4] All Kentucky samples are brown-rock phosphate.
[5] Ground material formerly sold for direct application to the soil.
[6] Museum sample.
[7] Commercial material as formerly produced.
[8] Bulow mines, Johns Island.
[9] Lamb's mine, near Charleston.

The estimated reserves of domestic phosphate rock, containing phosphoric acid equivalent to approximately 55 percent or more of tricalcium phosphate, amount to more than 6,231,318,000 long tons (table 1). The data given in tables 9 to 12 indicate that the average fluorine content of this rock is approximately 3.25 percent. On this basis, the estimated reserves of phosphate contain at least 200,000,000 tons of fluorine which, as pointed out by Marshall, Jacob, and Reynolds (*120*), is more than 75 times the fluorine content of the known reserves of fluorspar, containing 85 percent or more of calcium fluoride, in the Illinois and Kentucky deposits.

FOREIGN PHOSPHATE ROCK

The figures given in table 13 show that the north-African phosphates, particularly those from Algeria, Morocco, and Tunis, are characterized by very high fluorine-phosphoric acid ratios. In this respect they are similar to South Carolina phosphate (table 12).

The results of analyses (3.35 to 4.28 percent fluorine) obtained by the authors on the samples from Algeria, Morocco, and Tunis are, as a general rule, much higher than those (0.99 to 3.78 percent fluorine)

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reported by Carnot (*26*), Dussert (*43*), Gray (*58, p. 26–29*), and Parrish and Ogilvie (*136, p. 33*) on comparable grades of rock from these deposits.

TABLE 13.—*Fluorine content of phosphates from foreign continental deposits*

Sample no.	Location of deposit	P_2O_5	F[1]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
560	Algeria, Dyr	23.39	3.35	0.143
551	Algeria, Tebessa	26.10	3.43	.131
558	Algeria, Rebiba	26.84	3.65	.136
562	Algeria, M'Zaita	28.59	3.68	.129
557	Algeria, Tocqueville	29.38	3.71	.126
559	Algeria, Bordj-Redir	32.34	4.16	.129
555	Egypt, Kosseir	30.60	3.65	.119
453	Morocco [2]	33.47	4.15	.124
563	do	34.30	4.28	.125
1162	do	35.11	4.24	.121
552	Tunis, Gafsa	27.55	3.46	.126
556	Tunis, Kalaa-Djerda	26.91	3.48	.129
561	Tunis, M'Dilla	28.66	3.72	.130
553	Tunis, Gafsa	29.13	3.77	.129
1227	Belgium, Mons	12.18	1.61	.132
1226	Belgium, Liege	18.13	1.83	.101
1154	Estonia, Tallinn	16.78	1.49	.089
1155	do	25.68	2.44	.095
1156	do	26.48	2.38	.090
1228	France, Somme	22.02	2.89	.131
1240	do	24.66	3.37	.137
1241	France, Pyrenees Mountains	26.87	2.69	.100
1239	France, Quercy	34.74	.74	.021
1151	Portugal, Marvão	27.14	2.49	.092
1144	Prussia, Staffel, Nassau	33.89	3.62	.107
1152	Russia, Volga River region	13.40	2.02	.151
1265	Russia, Aktyubinsk, Siberia	17.42	2.50	.144
1263	Russia, Saratov	18.40	2.73	.148
1266	Russia, Egoriev	19.50	2.43	.125
1264	do	22.37	3.42	.153
1262	Russia, Viatka	27.88	3.85	.138
582	British Columbia, Crow's Nest Pass	24.11	2.64	.109
1258	Palestine, Nebl Moussa	8.14	.99	.122
1255	do	16.60	1.67	.101
1256	do	17.50	1.97	.113
1257	do	20.40	2.58	.126
1157	South Australia, Kapunda	30.18	3.62	.120
1158	South Australia, Port Clinton	23.53	3.32	.099

[1] Determined by the volatilization method (*153*).
[2] Samples from either the Boujniba or the Kourigha deposits, probably the latter.

In proportion to their phosphoric acid content, the samples of Russian phosphate rocks (table 13) contain even more fluorine than do the north-African phosphates. Next to those of the Russian phosphates, the highest fluorine-phosphoric acid ratios in samples from other European deposits were found in rocks from Mons, Belgium, and Somme, France. On the other hand, the sample (no. 1239) from Quercy, France, is comparatively low in fluorine (0.74 percent), although it contains 34.74 percent phosphoric acid. This analysis agrees closely with the one reported by Lacroix (*96*).

The fluorine-phosphoric acid ratios in the Estonian phosphates (table 13), which came from a deposit in the Obolus sandstone region near Tallinn (*130*), are somewhat lower than those usually found in continental phosphates.[9a] The material from this deposit is unusual in that the phosphatic portion consists of phosphatized shells. In their fluorine-phosphoric acid ratios (table 13), the samples of

[9a] The terms "continental phosphates", "continental rocks", and "continental deposits", as used in this publication, refer to phosphates, rocks, and deposits occurring on the continents, regardless of whether they are of continental or marine origin.

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phosphate rock from deposits in British Columbia, Palestine, and South Australia are similar to those from deposits in the United States.

The amounts of fluorine found in 17 samples of phosphate from deposits on eight widely distributed tropical islands (table 14) range from 0.06 percent in the hydrated aluminum phosphate (no. 904) from the Connetable Islands to 3.42 percent in one sample of Makatea Island phosphate. With the exception of the Connetable Islands phosphate, all the samples of insular rocks are calcium phosphates. As shown in tables 9 to 13, the fluorine-phosphoric acid ratios in phosphate rocks from continental deposits rarely fall below 0.09 and usually range from about 0.10 to 0.13. On the other hand, the ratios in phosphates from insular deposits are usually very much lower, rarely exceeding 0.09 and usually falling below 0.08. The ratios in phosphates from a particular island tend, however, to run quite uniformly, and in this respect the insular phosphates are similar to the individual varieties and types of continental phosphates. The ratios in the four samples of Curacao rock are unusually low, ranging from 0.0093 to 0.0240. In proportion to the phosphoric acid content, Curacao phosphate contains less fluorine than any of the other calcium phosphate rocks for which data are available.

TABLE 14.—*Fluorine content of phosphates from foreign insular deposits*

Sample no.	Location of deposit	P_2O_5	F [1]	$\frac{F}{P_2O_5}$
		Percent	*Percent*	
1223	Angaur Island [2]	40.00	2.96	0.0740
452	Christmas Island	39.46	1.32	.0335
1231	do	40.03	1.05	.0262
[3] 904	Connetable Islands	54.51	.06	.0011
1022	Curacao Island	37.89	.91	.0240
985	do	38.59	.70	.0181
984	do	38.71	.75	.0194
943	do	40.66	.38	.0093
1222	Juan de Nova Island [4]	32.29	1.68	.0520
1230	Makatea Island [5]	37.94	3.42	.0901
1159	do	38.22	3.25	.0850
450	Nauru Island	38.92	2.62	.0673
1232	do	39.06	2.48	.0635
1160	do	39.21	2.10	.0536
451	Ocean Island	40.32	2.97	.0737
1229	do	40.33	2.97	.0736
1161	do	40.87	3.29	.0805

[1] Determined by the volatilization method (*153*).
[2] Pelew Group.
[3] Aluminum phosphate; other samples are calcium phosphates.
[4] Off the east coast of Madagascar.
[5] Society Group.

PHOSPHATE MINERALS

The theoretical fluorine-phosphoric acid ratio in fluorapatite, $Ca_{10}F_2(PO_4)_6$, is 0.0891. Analyses of nine samples from widely separated deposits gave, however, ratios ranging from 0.0769 to 0.110, the average being 0.0916 (table 15). The ratios in fluorapatite are, as a general rule, lower than those in phosphate rocks from continental deposits, but higher than those in rocks from insular deposits. Fluorapatite usually contains small percentages of chlorine (*39, p. 765; 78, p. 566–571*) and the deficiency of fluorine in many samples is generally ascribed to replacement of the fluorine by chlorine or by the hydroxyl group. Replacement of fluorine by chlorine in apatite occurs, however, only to a limited extent (*65*).

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TABLE 15.—*Fluorine content of phosphate minerals, bones, and bird guano*

Sample no.	Material	Location of deposit	P_2O_5[1]	F[1]	$\frac{F}{P_2O_5}$
			Percent	*Percent*	
[2]1136	Fluorapatite	Virginia, Amherst County	38.12	2.93	0.0769
1261	do	Russia, Kola Peninsula	38.46	3.50	.0910
1260	do	do	39.08	3.49	.0893
646	do	Ontario, Renfrew County	39.63	3.84	.0969
647	do	do	39.77	3.89	.0978
633	do	do	39.88	3.88	.0973
648	do	New York, Hammond, St. Lawrence County.	38.58	4.24	.110
649	do	Mexico, Durango	40.86	3.44	.0842
905	do	Quebec Province	40.30	3.26	.0809
634	Chlorapatite	Norway, Kragerö	40.50	.17	--------
632	Amblygonite	California, Pala, San Diego County	44.45	4.02	--------
631	Wavellite	Pennsylvania, Mount Holly Springs, South Mountain.	33.62	3.95	--------
971	Bone ash, commercial material		40.36	.054	.0013
------	Bone meal, commercial material		--------	[3].05	--------
------	Modern bones and teeth [4]		40.17	.21	.0052
------	Modern swine femurs [5]		40.30	.03	.0007
------	do [6]		40.90	.86	.0210
------	Fossil bones and teeth [7]		30.68	1.85	.0603
643	Fossil fish teeth	Florida land-pebble phosphate district.	37.16	3.48	.0936
644	Fossil animal teeth	do	38.91	1.76	.0452
645	Fossil animal bones	do	37.29	3.29	.0882
1106	Bird guano	Islands belonging to Peru	14.40	.06	.0042

[1] Figures not corrected to moisture-free basis.
[2] Material obtained by magnetic separation from ilmenite nelsonite.
[3] Average of four samples.
[4] Average composition of ash of 20 samples from humans, quadrupeds, reptiles, and fish (*22*).
[5] Average composition of ash of 2 samples from animals receiving feeds low in fluorine (*7*).
[6] Average composition of ash of 6 samples from animals receiving feeds high in fluorine (*7*).
[7] Average composition of ash of 52 samples from animals and reptiles (*22*).

Carnot (*23*) reported that four samples of wavellite (aluminum phosphate) from Ireland and the United States contained 1.81 to 2.79 percent fluorine. These figures, also those given by Dana (*39, p. 842*), are much lower than that of 3.95 percent fluorine obtained by the authors on a sample of wavellite from Mount Holly Springs, South Mountain, Pa. (table 15). This particular deposit is of interest because the mineral was used at one time as a raw material for the manufacture of phosphorus (*190*). Dana states that wavellite does not always carry fluorine. Besides wavellite only a few of the mineral aluminum phosphates, among which may be mentioned amblygonite, a fluorphosphate of aluminum and lithium, contain significant quantities of fluorine. Fluorine was not found in samples of the mineral iron phosphates, dufrenite and vivianite. Dana does not record the occurrence of fluorine in any iron phosphate minerals.

BONES AND BIRD GUANO

Inasmuch as the phosphatic constituent of bone has a crystal structure similar to that of fluorapatite and phosphate rock (*64, 65*), data on the fluorine content of bone are of interest. No comprehensive investigation of this subject seems to have been made in recent years. Owing largely, no doubt, to the use of inaccurate analytical methods and to certain other complications, the existence of which has been recognized only recently, the data reported in the literature are somewhat conflicting, and it is difficult to draw from them conclusions as to the fluorine content of normal bone.

Perhaps the most extensive investigation of the subject was made about 1892 by Carnot (*19, 20, 21, 22*), who reported an average of 0.21

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percent fluorine in the ash of 20 samples of human, quadruped, reptile, and fish bones and teeth of the modern period. Bethke and coworkers (*7*) recently reported an average of 0.03 percent fluorine in the ash of two samples of femurs from swine fed on rations low in fluorine. However, when small quantities of fluorine compounds were added to the rations the fluorine content of the ash of the femurs increased considerably and roughly in proportion to the amount of fluorine in the feed, the results on six samples ranging from 0.53 to 1.10 percent, with an average of 0.86 percent fluorine. Likewise, Cristiani (*36*) found that the bones of cattle from districts where there were no factories discharging fluorine compounds into the atmosphere usually contained less than 0.05 percent fluorine, whereas the bones of cattle living in the neighborhood of aluminum works contained as much as 0.379 percent fluorine. This increase in the fluorine content of the bones resulted, no doubt, from the ingestion of herbage upon which fluorine compounds had been deposited from the atmosphere. Casares (*28*) reported that fluorine is not present in teeth, and that the bones of young animals contain less fluorine than those of old animals. On the other hand, Papish, Hoag, and Snee (*132*), using an indirect spectroscopic method, found fluorine in the bones and teeth of rats and pigs. The authors found an average of 0.05 percent fluorine in four samples of commercial bone meal and 0.054 percent in a sample of commercial bone ash (table 15). On the basis of these data, it would seem that fluorine is a normal constituent of the teeth and bones of animals, and that the normal fluorine content of bone is probably less than 0.1 percent. It is evident, furthermore, that the fluorine content of bone may be greatly increased by the ingestion of fluorine compounds.

The fluorine content of fossil bones and teeth is usually very much higher than that of modern bones and teeth. Samples of fossil fish teeth, animal teeth, and animal bones from the Florida land-pebble phosphate district contained 3.48, 1.76, and 3.29 percent fluorine, respectively (table 15). Carnot (*22*) analyzed 52 samples of ash from fossil animal and reptile bones and teeth of different geological ages and found that the fluorine content ranged from 0.44 to 3.62 percent, with an average of 1.85 percent. Carnot showed that the fluorine content of fossil bones increases with their age. Murray and Renard (*128, p. 488–495*) also observed that deep-sea fossil bones contain more fluorine than do modern marine bones.

The only published figures on the fluorine content of fresh bird guano that have come to the attention of the authors are those of Braun (*13*), who reported 0.05 to 0.34 percent fluorine in seven samples from deposits in various parts of the world. Three samples of fresh Peruvian guano, analyzed by Braun, contained 0.05 to 0.20 percent fluorine, whereas the authors found 0.06 percent fluorine in a sample of this material (table 15). It is evident from these figures that fresh bird guano contains in proportion to its phosphoric acid content very much less fluorine than is usually present in phosphate rock.

ORIGIN OF FLUORINE IN PHOSPHATE ROCK

Before considering the origin of the fluorine in phosphate rock, it is desirable to note briefly the possible sources of the phosphoric acid itself.

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The phosphoric acid content of the majority of the tropical-island deposits was no doubt derived from the leaching of soluble phosphates from bird guano into underlying deposits of calcium carbonate. The phosphoric acid in the guano was in turn derived from the fish ingested by the birds formerly inhabiting the islands, and also from the bones of the birds themselves. The source of the phosphoric acid in the continental deposits is not so clearly defined, but it seems certain that in many deposits it was not derived from bird guano. There is abundant evidence that fish and animal remains have played a part in the formation of some continental deposits, whereas phosphate-bearing marine organisms, such as certain of the brachiopods, undoubtedly contributed to the formation of certain deposits, for example those in Estonia (*130*).

In order to arrive at a satisfactory explanation of the origin of the fluorine in phosphate rock it is necessary to decide whether the fluorine was present in the phosphate as laid down in the original deposits or whether it resulted from secondary changes during or after the formation of the deposits. Therefore bones, bird guano, marine invertebrates, fluorine minerals, and water as sources of fluorine will be considered.

It has been shown herein that, in proportion to their phosphoric acid content, bird guano and fresh teeth and bones from animals receiving feed of normal composition probably contain less than one twentieth as much fluorine as is present in phosphate rock from continental deposits. Although it is true that fossil teeth and bones usually contain very much larger quantities of fluorine than do fresh teeth and bones, there is satisfactory proof that this condition results from secondary chemical changes occurring over very long periods of time. It seems, therefore, that the fluorine content of phosphate rock cannot be attributed solely to the fluorine originally present in the bird guano and in the fish and animal remains that may have played a part in the formation of the deposits.

As shown by Clarke and Wheeler (*33*), the inorganic phosphoric acid content of marine invertebrates ranges from less than 1 percent in the majority of the species to about 21 percent in certain annelids and 34 to 42 percent in certain phosphatic brachiopods. Clarke and Wheeler state, however, that marine invertebrates contain, as a general rule, only traces of fluorine. Carles (*16, 17*)[10] reported 0.0054 percent fluorine in oyster and marine mussel shells, whereas shells of fresh-water mussels and snails contained only 0.0009 to 0.0018 percent. On the basis of these data, it seems that the high fluorine content of phosphate rock can hardly he attributed to the fluorine in the marine organisms that may have played a part in the formation of some of the phosphate deposits. Furthermore, it seems that the greater portion of the fluorine present in phosphate rock was derived from a source or sources other than those supplying the phosphoric acid.

The authors are not aware that any of the phosphate-rock deposits are closely associated with deposits of fluorite and other fluorine-bearing minerals, and with a few exceptions (pp. 36 and 73) fluorite and fluorine compounds, other than the fluorphosphates, have not been found in phosphate rock. In the few cases where fluorite has

[10] In the original papers, Carles apparently expressed the results in terms of either sodium fluoride or calcium fluoride. On the assumption that his results are in terms of sodium fluoride, the corresponding fluorine equivalents have been calculated.

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been found in phosphate rock there is evidence that it is of secondary origin. These observations indicate that the fluorine content of phosphate rock did not originate, to any significant extent, from the action of phosphoric acid and soluble phosphates on deposits of fluorine-bearing minerals. Some phosphate rocks contain as high as 150 times as much fluorine as the figure, 0.027 percent, given by Clarke (*32, p. 34*) for the weighted average fluorine content of the lithosphere.

Finally, water may be considered as the possible source of the fluorine in phosphate rock. Comparatively little information on the fluorine content of water is available, and, because of analytical difficulties, it is probably unsafe to place much confidence in the older figures reported in the literature.

Although fluorine is rarely determined in water analysis, Clarke (*32, p. 193*) states that it is almost invariably present in water. According to Gautier and Clausmann (*53*), the fluorine content of 18 samples of water from French rivers and lakes ranged from less than 0.010 to 0.60 mg per liter. The same authors (*54*) found 0.154 to 6.32 mg of fluorine per liter in 45 samples of mineral waters from various localities in Europe and north Africa, the average being 2.06 mg. Carles (*15*) reported 0.00 to 8.14 mg per liter in 92 samples of French natural mineral waters, the average being 3.17 mg (footnote 10.) Churchill (*30*) recently made a survey of the fluorine in potable waters from various parts of the United States. The fluorine content of five samples from Arkansas, Colorado, Idaho, and the Dakotas ranged from 2.0 to 13.7 mg per liter, the average being 8.94 mg. Waters from other localities west of the Appalachian Mountains contained less than 1 mg of fluorine per liter. No fluorine was found in waters east of the Appalachians. Clarke (*31, p. 114*) reported 5.2 mg of fluorine per liter in a sample of water from Ojo Caliente, near Taos, N.Mex. According to Gautier and Clausmann (*54*), the fluorine content of three samples of water from the Atlantic Ocean and Mediterranean Sea ranged from 0.240 to 0.334 mg, with an average of 0.291 mg. Carles (*15*) found 5.43 mg of fluorine per liter in a sample of water from the Bassin d'Arcachon, Bay of Biscay. In addition to the foregoing, two important papers (*185a, 193a*) on the occurrence of fluorine in water have recently been published.

In 1891 Murray and Renard (*128, p. 275*) advanced the theory that the high fluorine content of fossil bones and teeth from deep-sea deposits owes its origin to a continuous, though slowly progressing, double decomposition between the phosphate of the bones and teeth and the traces of dissolved fluorides in sea water. A similar theory was advanced by Carnot (*22*) two years later, who showed that when fragments of bone, originally containing 0.31 percent flourine, were kept in contact with a 2 percent solution of sodium flouride for five months the fluorine content increased to 4.74 percent. As pointed out by Carnot, this theory gives an adequate explanation of the high fluorine content of fossil bone as compared with that of modern bone. Carnot also found that the fluorine content of fossil bone shows, in general, a marked tendency to increase with increase in the geological age of the bone (*19, 20, 21, 22*), and he points out that this is consistent with the theory that the bones take up fluorine from the waters with which they come in contact.

It seems to be the general opinion that the fluorine in the fossil brachiopod shells, principally *Obolus apollinis*, which are the main

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source of the phosphoric acid in the phosphate deposits near Tallinn, Estonia, was an original constituent of the shells (*130*). Unfortunately, no information on the fluorine content of the fresh shells of *O. apollinis* seems to be available, but there is no reason to believe that the shells are radically different in this respect from other marine invertebrates which contain only minute quantities of fluorine. In the light of present knowledge, it is more logical to suppose that the fluorine in the fossil shells, like that in fossil bone, is of secondary origin, and that it results from long contact of the phosphatic shells with fluorine-bearing waters.

Although the relation between fluorine content and geological age is not so pronounced in phosphate rock as in fossil bone, it has been pointed out (*120, 152*) that the insular phosphate rocks which belong to recent geological periods contain, in general, much less fluorine than do the continental rocks which belong to older geological periods and, therefore, have been exposed for a much longer time to the action of fluorine-bearing waters. If we assume that the fluorine in phosphate rock is derived principally from sea water and that the average fluorine content of the water is 0.291 mg per liter,[11] it would require approximately 120,000 liters of water to supply the fluorine that is present in 1 kg of phosphate rock containing 3.5 percent fluorine.

It is beyond the scope of this publication to give an extended discussion of the chemical reactions involved in the formation of the phosphate-rock deposits as they exist today. It should be pointed out, however, that the reactions were undoubtedly quite complex and extended over very long periods of time. It is probable that during the intermediate stages of the process a considerable portion of the phosphate, if not all, was present as calcium hydroxyphosphate, $Ca_{10}(OH)_2(PO_4)_6$, and calcium carbonate-phosphate, $Ca_{10}(CO_3)(PO_4)_6$. Upon exposure to fluorine-bearing waters, these compounds were converted into the less-soluble calcium fluorphosphate, $Ca_{10}F_2(PO_4)_6$, through the replacement of the carbonate and hydroxyl groups by fluorine. In the old continental deposits, such as those in the United States, it appears that complete transformation into fluorphosphate has occurred, whereas in the comparatively young insular deposits the transformation is, as yet, incomplete.

There seems to be little doubt that water is the principal source of the fluorine in phosphate rock. In this connection the question of the source of the fluorine in water naturally arises. Although this subject has not been extensively investigated, Zies (*210*) expresses the opinion that volcanic activity is a very important factor in the distribution of fluorine. His investigations of the Valley of Ten Thousand Smokes, in the Katmai region of Alaska, indicate that in this area alone approximately 180,000 metric tons of fluorine in the form of hydrofluoric acid are discharged into the atmosphere annually, and that approximately 75 percent of this quantity, or 135,000 metric tons, finds its way into the sea. The investigations of Churchill (*30*), Carles (*15*), and Gautier and Clausmann (*53, 54*) have shown that spring and river waters from areas far from scenes of volcanic activity frequently carry appreciable quantities of fluorine. In such cases the fluorine is no doubt derived from contact of the waters with fluorine-bearing minerals.

[11] This figure is the average of three results reported by Gautier and Clausmann (*54*).

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CHLORINE, BROMINE, AND IODINE

Very little information on the chlorine content of domestic phosphate rock appears in the literature. Eldridge (*44*) reported 0.08 percent chlorine in a sample of Florida hard-rock phosphate containing 33.91 percent phosphoric acid. The presence of chlorine has also been observed in the phosphates of South Carolina (*163*, *182*) and in those of Montana, Idaho, Utah, and Wyoming (*51*, *134*).

The data given in tables 3 to 6 indicate that chlorine is a common constituent of phosphate rock. It occurs, however, only in small quantities, usually less than 0.02 percent of the sample. Occasional samples, such as Florida soft phosphate (no. 580, table 3) and the Curacao Island phosphates (table 6) contained 0.12 to 0.16 percent chlorine. Of the domestic types of phosphate, Florida hard rock generally contains the lowest percentages of chlorine and the western phosphates, particularly the Idaho and Wyoming rocks, the highest. According to Clarke (*32. p. 34*), the average chlorine content of igneous rocks is 0.048 percent and of limestones 0.02 percent, whereas the weighted average chlorine content of the lithosphere is 0.045 percent. Sandstones contain only traces of chlorine. It is evident, therefore, that chlorine, unlike fluorine, does not tend, in general, to concentrate in phosphate rock.

The results for bromine in three samples, the only analyses made, ranged from less than 20 parts per million in Florida land pebble (no. 910) to 30 parts per million in Florida hard rock (no. 932). A sample of Tennessee brown rock also contained 30 parts per million of bromine. Although it is believed that these results are reasonably accurate, it is not safe to draw from the limited data general conclusions on the bromine content of phosphate rocks.

Only a few figures on the bromine content of rocks in general are available. In five of nine samples of meteorites tested, Fellenberg (*46*) found bromine in amounts ranging from 2 to 56 parts per million, the quantities being much larger in stone than in iron meteorites. Fellenberg and Lunde (*47*) reported 2 and 8 parts per million of bromine, respectively, in one sample each of granite and basalt. Data on the bromine content of sedimentary rocks have not come to the attention of the authors. Our results, when compared with those of Fellenberg, indicate, however, that phosphate rock probably contains, as a general rule, more bromine than is usually present in igneous rocks.

During the last few years numerous data on the iodine content of various fertilizer materials have appeared in the literature. The results have been summarized in part by Orr and Leitch (*131*) and also by McHargue, Roy, and Pelphrey (*110*). All available data on phosphate rock have been summarized by Hill and Jacob (*70*). The majority of the analyses have been made on foreign phosphates, and the figures, as a rule, are not very consistent for rocks of a given type or from a given locality. On the foreign phosphates, the published results range from approximately 1 part per million of iodine in Podolia phosphate (*207*) and in certain samples of Egyptian and Nauru Island phosphates (*67*) to 280 parts per million in rock from Limburg, Germany (*207*). In the domestic phosphates, McHargue (*109*) reported 5.45 and 6.72 parts per million of iodine in samples of brown-rock phosphates from Tennessee and Kentucky, respectively. Wilke-Dörfurt, Beck, and Plepp (*207*) reported 3.8 parts per million

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of iodine in a sample of Florida pebble phosphate and 54.5 and 92.5 parts per million in two samples of Florida hard rock.

Analyses of 30 samples from all the present commercially important deposits in the United States (table 16) indicate that iodine is a common constituent of the domestic phosphates. The results range from 0.8 part per million in rocks from Garrison, Mont., and Cokeville, Wyo., to 130 parts per million in one sample of Florida hard rock. Although the iodine content of domestic phosphate does not run very constant for a particular type of rock, samples of a given type or from a given locality seem to be characterized, as a general rule, by certain more or less definite limits in iodine. The averages of the results obtained on the domestic materials indicate that the western phosphates contain the smallest quantities of iodine, and are followed in order by Tennessee blue rock, Florida land pebble, Tennessee brown rock, Florida soft and waste-pond phosphates, and Florida hard rock.

TABLE 16.—*Iodine content of natural phosphates*

UNITED STATES DEPOSITS

Sample no.	Type or source of phosphate	P_2O_5	Iodine
		Percent	*Parts per million*
619	Florida land pebble	30.98	10.3
910	do	31.09	10.9
947	do	31.28	13.1
439	do	33.22	15.4
912	do	35.37	8.2
771	Florida hard rock	31.25	72.0
589	do	34.68	93.2
434	do	35.33	87.0
932	do	35.99	130
728	Florida soft	31.80	88.3
726	Florida waste pond	23.48	50.8
915	do	23.63	63.5
[1] 56	Tennessee brown rock	31.28	9.8
762	do	33.73	18.1
1233	do	33.73	17.3
906	do	34.39	28.2
908	do	34.44	16.3
772	Tennessee blue rock	30.45	5.4
930	do	30.97	6.4
[2] 1049	do	31.22	3.0
1031	Tennessee white rock	35.80	20.6
454	Idaho	32.24	2.6
973	do	32.53	1.9
1009	Montana	31.39	.8
1010	do	37.47	.8
948	Wyoming	30.19	.8
1235	Kentucky brown rock	21.19	9.5
1234	do	27.80	6.1
1139	South Carolina land rock	26.92	3.7
1138	do	27.85	13.9

NORTH-AFRICAN DEPOSITS

562	Algeria	28.59	3.7
1162	Morocco	35.11	113
552	Tunis	27.55	4.7
561	do	28.66	8.0

ISLAND DEPOSITS

452	Christmas Island	39.46	75.4
904	Connetable Islands	54.51	<1.0
985	Curacao Island	38.59	122
943	do	40.66	37.0
450	Nauru Island	38.92	16.5
451	Ocean Island	40.32	18.3

[1] Bureau of Standards standard sample no. 56.
[2] Kidney phosphate; other blue-rock samples are bedded phosphates.

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Three samples of Algerian and Tunisian phosphates contained 3.7 to 8.0 parts per million of iodine (table 16), the results being in good agreement with those previously reported (*207*). A sample of Moroccan phosphate contained 113 parts per million of iodine, a figure more than twice as high as that reported by Wilke-Dörfurt and coworkers (*207*). The results obtained on the samples of insular phosphates indicate that these materials are richer in iodine than are most continental phosphates. However, the aluminum phosphate from the Connetable Islands contained very little iodine (less than 1 part per million). This material also contained only very small quantities of fluorine and chlorine (table 6). A summary of all available data (*70*), including those obtained in this investigation, shows that the iodine content of 71 samples of phosphate rock from all parts of the world ranged from 0.8 to 280 parts per million, with an average of 31.3.

Hill and Jacob (*70*) have shown that, so far as increase in the iodine content with the age of the rock is concerned, there is no regular relation between the geological age and the iodine content of phosphate rock. They pointed out, however, that the phosphates from western United States, which are only sparingly fossiliferous, are very low in iodine, whereas certain other deposits which contain fossil remains in abundance are comparatively high in iodine. This observation is in line with the results obtained by Fellenberg (*45*) on rocks in general. One might infer from this that the iodine in phosphate rock is associated with organic matter, and that, consequently, a definite relation between the iodine and organic matter in phosphate rock might be expected. Such a relation is not indicated, however, by the data in tables 16 and 18. In fact, in a particular type of rock, samples containing the largest quantities of organic matter more often than not contain the smallest quantities of iodine. The comparison shows also that although the sparingly fossiliferous Idaho and Wyoming phosphates contain less than 4 percent as much iodine as does Florida hard rock they contain 4 to 15 times as much organic carbon. The source of the carbon in these materials is not known, but microscopical examination of Idaho phosphate no. 973 and Wyoming phosphate no. 948, by W. H. Fry, of the Bureau of Chemistry and Soils, showed the presence of plantlike fragments.

No trace of iodine was found in the organic matter separated from Florida land pebble (no. 912), Florida hard rock (no. 932), Tennessee brown rock (no. 906), and Idaho rock (no. 973) by heating 5-gram samples to boiling in about 10 minutes with 125 cubic centimeters of 1 to 1 hydrochloric acid, and washing the residues with 1 to 20 hydrochloric acid. However, these findings should be considered as only indicatory inasmuch as iodine-bearing organic matter, if present, may be hydrolyzed by acids, with the result that the iodine passes into solution.

It is not inconsistent with the chemistry of the complex calcium phosphate-halogen compounds to postulate that the iodine in phosphate rock is present in the form of a calcium iodophosphate similar, perhaps, to the chlor- and fluorphosphates. In fact, Ditte (*42*) claims to have prepared, by a high-temperature method, a complex calcium iodophosphate. Wilke-Dörfurt, Beck, and Plepp (*207*) were unable to duplicate Ditte's results, but the compounds they obtained always showed, nevertheless, small percentages of water-insoluble iodine. If

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a calcium iodophosphate is present in phosphate rock it would be easily soluble in mineral acids.

Although the source of the iodine in phosphate rocks is not so clearly defined as is that of the fluorine, it is possible that a portion of the iodine was derived from waters with which the phosphates have come in contact during and after their deposition. There is considerable variation in the published figures on the iodine content of ocean and sea water. The older results, which have been summarized by Clarke (*32, p. 122*), show a range of 0.02 to 2.83 parts per million of total iodine, whereas Reith (*149*) has recently reported that 13 samples of ocean and sea waters, taken from various localities and at different depths, contained an average of 0.0542 part per million.

Comparing the iodine content of phosphate rock with that of other rocks, and also of soils, is interesting. The average of Fellenberg's results (*45, p. 209*) on 30 samples of igneous rocks, pyromorphite, quartzite, anhydrite, gypsum, calcite, limestone, marble, and dolomite, is 0.91 part per million of iodine. Two samples of fluorapatite contained an average of 0.370 part per million of iodine. Hercus, Benson, and Carter (*66, p. 332*) reported that the iodine content of 473 samples of New Zealand soils ranged from 0.0 to 70.0 parts per million, the average being 2.7 parts per million. McHargue and others (*111*) found 0.103 to 8.250 parts per million of iodine in 16 samples of soil from Canada, Kentucky, New Jersey, and South Carolina, the average being 4.538 parts per million. It is evident, therefore, that phosphate rock contains, in general, much more iodine than is usually present in other rocks, both igneous and sedimentary, in soils, and in ocean and sea waters.

SULPHUR

Appreciable amounts of sulphur are present in all domestic phosphate rocks (tables 3, 4, 5, and 17). Of a given type of phosphate, the samples relatively high in phosphoric acid usually contain the smallest percentages of sulphur. Florida hard-rock, soft, and waste-pond phosphates, pyrite-free Tennessee brown rock, and Montana phosphate consistently show less than 1 percent of total sulphur (as SO_3), whereas Tennessee blue rock is much richer in this element than are any of the other types of phosphate for which data are available. The total sulphur content (0.56 percent SO_3) of Florida hard rock no. 932 (table 17) is unusually high for this type of phosphate. On three other samples the percentages ranged from 0.12 to 0.16, which is in good agreement with the results on four samples as reported by Clarke (*32, p. 533*).

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TABLE 17.—*Sulphur content of phosphate rock*

Sample no.	Type or source of phosphate	P_2O_5	Total sulphur as SO_3	Fractional forms of sulphur as SO_3				Total sulphur minus sum of fractional determinations
				Sulphate soluble in 1 to 4 hydrochloric acid	Sulphate insoluble in 1 to 4 hydrochloric acid	H_2S evolved with 1 to 4 hydrochloric acid	Sulphide insoluble in 1 to 4 hydrochloric acid	
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
618	Florida land pebble	30.53	1.42	1.14	0.20	0.04	(1)	0.04
617	do	30.70	1.51	1.19	.13	.05	0.02	.12
619	do	30.98	1.29	1.06	.07	.04	(1)	.12
910	do	31.09	1.05	.98	.00	.05	(1)	.02
947	do	31.28	1.22	1.09	.05	.03	(1)	.05
790	do	31.40	1.36	1.19	.00	.03	.00	.14
627	do	33.70	1.08	.85	.01	.01	(1)	.21
912	do	35.37	.26	.20	.00	.05	(1)	.01
932	Florida hard rock	35.99	.56	.01	.00	.00	.00	.55
[2] 56	Tennessee brown rock	31.28	2.69	1.24	.00	Trace	1.19	.26
762	do	33.73	.81	.75	.00	.00	.00	.06
906	do	34.39	.71	.59	.02	.00	.00	.10
908	do	34.44	.76	.68	.02	.00	.00	.06
772	Tennessee blue rock	30.45	7.10	4.02	.06	Trace	2.71	.31
930	do	30.97	6.64	1.26	.01	Trace	5.21	.16
[3] 1049	do	31.22	4.07	2.00	(1)	Trace	2.02	.05
448	do	32.02	4.04	2.43	.02	Trace	1.37	.22
449	do	33.65	4.37	1.06	.00	Trace	3.19	.12
916	Tennessee phosphatic limestone	11.22	2.57	1.55	(1)	Trace	.97	.05
917	do	11.68	4.84	2.27	(1)	Trace	2.52	.05
550	Idaho	32.21	1.53	1.43	.00	.05	.00	.05
454	do	32.24	2.52	1.66	.00	.05	.00	.81
973	do	32.53	2.47	1.69	.05	.10	.00	.63
1009	Montana	31.39	.33	.12	.02	.00	.02	.17
1010	do	37.47	.38	.26	.02	.00	.02	.08
948	Wyoming	30.19	3.09	1.30	.05	.09	1.30	.35
1139	South Carolina land rock	26.92	2.51	1.74	.00	Trace	.48	.29
1138	do	27.85	2.65	1.97	.00	Trace	.46	.22
552	Tunis, Gafsa	27.55	3.53	2.87	.07	.00	.00	.59
1162	Morocco	35.11	1.46	1.40	(1)	.00	.00	.06

[1] Not determined.
[2] Bureau of Standards standard sample no. 56.
[3] Kidney phosphate.

Previous data on the total sulphur content of Florida land-pebble and Tennessee brown-rock phosphates have not come to the authors' attention. A few results for sulphur, presumably total sulphur, in several other domestic types of phosphate have been reported in the literature. Thus, the range of the results (SO_3) on three samples from different localities in Idaho (*99; 119, p. 210; 143*) is 1.77 to 2.74 percent. Pardee (*134*) found 2.10 percent in one sample of Montana phosphate; Mansfield (*119, p. 210*) reported 2.34 and 2.98 percent in two samples of Utah rock; and the results on phosphate from South Carolina (*126, 127, 137*) ranged from 0.25 to 2 percent, expressed as SO_3. Small amounts of sulphur, 0.08 to 0.66 percent, have been reported in the phosphates from Johnson County, Tenn. (*90*), and traces have been found in North Carolina (*40*) and Oklahoma (*179, 180*) phosphates.

Relatively little information on the condition of the sulphur in phosphate rock is available. Published figures for sulphur trioxide in Florida land pebble (*58, p. 30*) range from 0.42 to 1.60 percent, with an average of 0.86 percent. The average of Memminger's results for sulphate sulphur (SO_3) on four samples of commercial Tennessee blue rock (black phosphate) is 2.70 percent, the range being 2.30 to 3.32 percent (*124*). The same author's results for

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pyritic sulphur in 14 samples of this material range from 0.40 to 3.71 percent in terms of SO_3, the average being 2.09 percent. In five samples of commercial blue rock, Hook (*81*) reported quantities of pyrite equivalent to 0.99 to 2.71 percent SO_3, with an average of 1.99 percent. Jones (*92*) found 2.24 percent sulphate and 1.72 percent iron sulphide in a sample of phosphate from Woodruff Creek, Rich County, Utah. Shepard (*182*) stated that the South Carolina phosphates rarely contain more than 1 percent of iron pyrites.

Table 17 shows that a considerable portion of the total sulphur is present as sulphate in all phosphates analyzed, except Florida hard rock. Furthermore, the sulphur is usually present in more than one inorganic form. Small quantities of acid-insoluble sulphate frequently occur, particularly in Florida land pebble. On treatment with acid, measurable quantities of hydrogen sulphide were evolved from Florida land pebble, and somewhat larger amounts from Idaho and Wyoming phosphates. This form of sulphur was not found in Florida hard rock, pyrite-free Tennessee brown rock, Montana, north-African, and the island phosphates. Relatively large amounts of pyritic sulphur are present in Tennessee blue rock and phosphatic limestone. The range of results on the former, 1.37 to 5.21 percent in terms of SO_3, is considerably higher than the range of previous figures for pyritic sulphur in blue rock. Somewhat smaller percentages of acid-insoluble sulphide were found in South Carolina and Wyoming phosphates and in one sample of Tennessee brown rock. Florida land pebble and hard rock, most samples of Tennessee brown rock, and the Montana, Idaho, and north-African phosphates do not contain significant quantities of acid-insoluble sulphide.

A comparison of the results for total sulphur with the sum of the results for the four inorganic forms of sulphur (table 17) shows that not all the sulphur is recovered in the fractional determinations. As indicated in the last column of this table, the differences range from 0.01 percent on Florida land pebble to 0.81 percent on phosphate from Conda, Idaho. Moreover, the greatest differences occur in material rich in organic carbon (table 18). In view of this and the fact that the organic material separated from several types of phosphate is relatively high in sulphur (table 20), it is concluded that the figures in the last column of table 17, aside from the relatively small analytical errors accumulated therein, give a good indication of the amounts of organic sulphur present in these materials. It has been shown in a recent paper (*74*) that the figures for organic sulphur arrived at in this manner are usually in good agreement with those obtained for acid-insoluble organic sulphur, as determined by Eschka's method on the rock residue insoluble in hydrochloric acid (1 to 4).

ORGANIC MATTER, NITROGEN, AND WATER

The presence of appreciable quantities of organic matter in domestic phosphate rock is well known, but very few quantitative figures on its occurrence are available. Clarke (*32, p. 553*) reported 0.12 to 0.22 percent of organic carbon in three samples of Florida hard rock. With the exception of these figures, the available data, so far as the authors are aware, are limited to qualitative results and figures for "organic matter and combined water," as determined from the ignition loss. The phosphates of Idaho, Utah, and Wyoming contain relatively large amounts of organic material, which in some instances is oil-

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bearing (*119, p. 211*). Nitrogen, in amounts ranging from a trace to 0.21 percent, has been reported in South Carolina phosphates (*127*).

Results for organic carbon in 29 samples of phosphate rock, as determined by the combustion method, are given in table 18. Except the burning of pyrite-bearing materials at 600° C., the combustions were made at 800° C., and the figures thus obtained were corrected for any carbon dioxide evolved from carbonates during the heating. Elemental carbon, if present, is included with the organic carbon.

TABLE 18.—*Organic carbon, nitrogen, and total water in phosphate rock*

Sample no.	Type or source of phosphate	P_2O_5	Organic carbon[1]	Nitrogen	Total water[2]
		Percent	*Percent*	*Percent*	*Percent*
619	Florida land pebble	30.98	0.33	0.018	2.27
[3] 910	do	31.09	.33	.006	2.57
947	do	31.28	.29	.008	2.49
439	do	33.22	.25	([4])	1.88
[3] 912	do	35.37	.38	.013	1.35
771	Florida hard rock	31.25	.52	.018	3.40
[3] 932	do	35.99	.18	.005	1.48
[3] 728	Florida soft	31.80	.16	.018	3.85
[3] 726	Florida waste pond	23.48	.22	.024	5.81
915	do	23.63	.47	.044	8.18
[5] 56	Tennessee brown rock	31.28	[6] .25	.023	[6] 1.66
762	do	33.73	.29	.015	1.39
[3] 906	do	34.39	.09	.006	1.29
[3] 908	do	34.44	.11	.004	1.31
772	Tennessee blue rock	30.45	[6] .36	.034	[6] 1.84
[3] 930	do	30.97	[6] .20	.021	[6] 1.06
[3,7] 1049	do	31.22	[6] 1.46	.26	[6] 2.42
[3] 1048	Tennessee white rock	30.20	.09	.016	1.55
[3] 1031	do	35.80	.26	.033	2.53
454	Idaho, Conda	32.24	2.29	.091	1.96
[8] 973	do	32.53	2.35	.10	1.90
[3] 1009	Montana, Garrison	31.39	.14	.008	1.10
[3] 1010	do	37.47	.09	.008	.60
[3] 948	Wyoming, Cokeville	30.19	[6] 2.69	.11	[6] 1.50
1138	South Carolina land rock	27.85	[6] .51	.051	[6] 3.31
552	Tunis, Gafsa	27.55	.86	.047	3.05
1162	Morocco	35.11	.17	.018	1.44
985	Curacao Island	38.59	.17	.013	2.29
[3,9] 904	Connetable Islands	54.51	.28	.049	1.68

[1] Including elemental carbon.
[2] Unless indicated otherwise, these figures are for total water at 800° C. and do not include water driven off at 105° C.
[3] Air-dried material.
[4] Not determined.
[5] Bureau of Standards standard sample no. 56.
[6] Determination made at 600° C.
[7] Kidney phosphate.
[8] Crushed rock dried in a coal-fired rotary kiln.
[9] Hydrated aluminum phosphate. Sample lost 22.58 percent water when heated to constant weight at 105° C.

It will be noted that the phosphates from Conda, Idaho, and Cokeville, Wyo., are by far the richest in organic carbon. Whereas the carbon content of these samples ranges from 2.29 to 2.69 percent, the Tennessee kidney phosphate (no. 1049) is the only other sample that contains more than 1 percent. The results on the other samples of domestic phosphates range from 0.09 to 0.52 percent, and this range also includes the samples of Morocco and Curacao and Connetable Islands phosphates.

Before being used in the manufacture of phosphoric acid by the sulphuric acid process, the Conda, Idaho, rock is calcined at about 700° C. to remove the major portion of the organic matter, which would otherwise seriously foul the acid and apparatus (*99*). When Florida pebble phosphate is treated with dilute sulphuric acid for the

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manufacture of phosphoric acid, the foam formed by the evolution of carbon dioxide is stabilized to such an extent by the organic matter present in the rock that it sometimes seriously interferes with factory operation. Formation of a stable foam may be prevented by adding small quantities of crude mineral oil to the mixing vessel (*72*). Some of the pebble-phosphate mining companies calcine the rock to remove organic matter and other volatile constituents (*125*).

The materials richest in carbon also contain the largest percentages of nitrogen (table 18). Thus, the nitrogen figures for Idaho and Wyoming phosphates are approximately 0.1 percent, and that for the sample of Tennessee kidney phosphate (no. 1049) is 0.26 percent, in comparison with a range of 0.004 to 0.051 percent for all other samples analyzed. As indicated by its light color, phosphate from Paris, Idaho, carries much less organic matter than that from the Conda locality, and it may be noted in this connection that a sample of the Paris phosphate, not included in table 18, contained only 0.02 percent of nitrogen.

Figures for total water, exclusive of moisture driven off at 105° C., are given in the sixth column of table 18. The results were obtained in connection with the organic-carbon determinations and therefore include water derived from combustion of organic matter. Because of the uncertainty as to whether all the combined water is driven off at the temperatures employed in the carbon determinations, the figures may be somewhat low. Excluding results on the Florida soft and waste-pond phosphates, the results for total water range from 0.6 percent in high-grade Montana phosphate (no. 1010) to 3.4 percent in low-grade Florida hard rock (no. 771). Tennessee brown rock contains, in general, less water than the other types of phosphate, except Montana phosphate. As would be expected, the Florida soft and waste-pond phosphates show considerably higher percentages of water than do the rock phosphates.

Organic carbon in several samples was determined by isolation and combustion according to the method recommended by Fieldner, Selvig, and Taylor (*48*) for the analysis of carbonate rocks. As pointed out in a previous paper (*74*), any soluble organic material is lost in the filtrates, and losses may also occur as a result of hydrolytic and oxidation processes during the digestion with acid and the subsequent filtration and washing. In comparison with the figures obtained by direct combustion of the rocks, the results given in the fourth column of table 19 indicate considerable losses of carbon in Florida land pebble and hard rock as a result of the isolation treatment. The results by the two methods are in very good agreement, however, on Tennessee brown and blue rock and Idaho phosphate.

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TABLE 19.—*Combined water in phosphate rock*

Sample no.	Type or source of phosphate	Organic carbon		H_2O		Total H_2O by combustion at 800° C.	Combined H_2O
		By direct combustion of rock	By isolation and combustion	From combustion of isolated organic matter	Equivalent to organic C found by direct combustion [1]		
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
[2] 910	Florida land pebble	0.33	0.18	0.14	0.26	2.57	2.31
[2] 912	do	.38	.11	.12	.41	1.35	.94
771	Florida hard rock	.52	.24	.16	.35	3.40	3.05
[2] 932	do	.18	.06	.04	.12	1.48	1.36
[2] 906	Tennessee brown rock	.09	.11	.04	.03	1.29	1.26
[2] 908	do	.11	.14	.07	.06	1.31	1.25
[2] 930	Tennessee blue rock	.20	.28	.16	.11	[3] 1.06	.95
454	Idaho	2.29	2.33	.85	.84	1.96	1.12
[4] 973	do	2.35	2.22	.77	.82	1.90	1.08

[1] Calculated on the assumption that the ratio of H_2O to C is the same in the isolated organic material as in that present in the original rock.
[2] Air-dried material.
[3] Combustion at 600° C.
[4] Crushed rock dried in a coal-fired rotary kiln.

Assuming that the ratio of water to organic carbon is the same in the isolated material as in the organic matter originally present in the rock, the water equivalent to the organic carbon found in the original rock by direct combustion may be calculated. If the figure thus obtained is subtracted from the total water found by direct combustion of the sample, a figure is obtained indicative of the amount of water associated with the inorganic constituents of that particular sample. The results for combined water given in the last column of table 19 were obtained in this way. Despite the accumulation of errors in these figures, as discussed elsewhere (*74*), it is the opinion of the authors that they give a good indication of the amounts of combined water which may be expected in the domestic phosphate rocks. Although these analyses indicate a range of about 1.0 to 1.5 percent in most types of phosphate, the lower grades of Florida land pebble and hard rock contain larger quantities of combined water.

Large-scale separations of the organic matter were made on five representative samples of commercial phosphates, using the procedure of Fieldner, Selvig, and Taylor (*48*). The greater portion of the quartz was removed by decantation during the early stages of the separations, and the isolated organic matter was dried at 105° C. The elementary analyses of the isolated materials (table 20) indicate that the composition of the organic matter present in different types of phosphate rock varies within rather wide limits. In particular, the material obtained from Florida hard rock is characterized by relatively low percentages of carbon and nitrogen, and by very high percentages of sulphur and ash. Furthermore, the results on the two samples of Florida land pebble indicate that the composition, especially the carbon content, of the material isolated from different samples of the same type of phosphate may also be subject to considerable variation. In all cases, iron oxide was the principal constituent of the ash of the isolated materials.

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TABLE 20.—*Composition of organic material isolated from phosphate rock*

Sample no.	Type or source o phosphate	Weight of rock used in separation	Color of organic material	Elementary analysis				
				Ash [1]	C	H	N	S
		Grams		*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
910	Florida land pebble	200	Dark brown	2.50	63.3	5.26	3.41	7.32
912	do	200	do	12.6	53.1	4.39	1.88	10.2
932	Florida hard rock	400	Brownish black	50.2	22.6	2.08	.16	39.1
908	Tennessee brown rock	400	Dark brown	9.53	60.8	3.41	3.15	8.11
[2] 973	Idaho	30	Black	2.32	61.3	2.62	2.07	7.90

[1] Principally iron oxides.
[2] Crushed rock dried in a coal-fired rotary kiln; other samples were air-dried.

The data in tables 3 to 6 show that, on a number of samples, figures for ignition loss are given instead of those for total water plus organic carbon and nitrogen. When corrected for the carbon dioxide present as carbonates in the original sample, the figures for ignition loss are often considered to indicate the amounts of combined water and organic matter present. It has been shown (*74*), however, that in the case of phosphate rock the value of this determination is vitiated by the volatilization of fluorine and silicon, which becomes serious at temperatures as low as 1,000° C. and progressively increases at higher temperatures; by incomplete decomposition of the carbonates at 1,000° C., as much as 1 percent of carbon dioxide sometimes remaining in the residue after ignition to constant weight at this temperature; and by the erratic behavior of pyrite, which is a common constituent of some types of phosphate. The figures for ignition loss given in the tables have been corrected for the total carbonate carbon present in the original samples, but not for the volatilization of fluorine and silicon and for the carbon dioxide remaining after ignition. With samples containing pyrite, the figures for ignition loss have also been corrected for the oxidation of pyritic sulphur, as determined from analyses of the original samples and the ignition residues (*74*).

Data on the percentages of moisture lost from various types of phosphates upon drying to constant weight at 105° C. are given in table 21. Excluding the results on the Florida soft and waste-pond phosphates, the results indicate that the moisture content of phosphate rock usually ranges from about 0.30 to 1.25 percent. The range is higher in South Carolina land rock and lower in Montana rock. The samples include both air-dried and commercial kiln-dried materials. On the basis of their moisture content, however, no distinction can be made between the kiln-dried and air-dried samples of a particular type of rock. When rock that has been kiln dried by the customary commercial methods is allowed to remain in contact with the air until equilibrium with the atmospheric moisture is established it will contain approximately the same percentage of moisture as will an air-dried sample of the same rock.

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TABLE 21.—*Moisture content of phosphate rock*

Type or source of phosphate	Samples analyzed	H_2O driven off at 105° C.	
		Range	Average
	Number	*Percent*	*Percent*
Florida land pebble	11	0.50–1.05	0.72
Florida hard rock	4	.50–1.27	.73
Florida soft	4	.44–2.80	1.32
Florida waste pond	3	2.51–3.48	3.07
Tennessee brown rock	6	.38– .82	.65
Tennessee blue rock	5	.46–2.34	1.07
Tennessee white rock	2	.30– .48	.39
Tennessee phosphatic limestone	2	.39– .52	.45
Idaho	3	.50–1.27	.89
Montana	3	.20– .42	.28
Wyoming	1	----------	.35
South Carolina land rock	2	.80–1.89	1.35
Island deposits [1]	5	.28– .88	.49
Tunis, Gafsa	1	----------	2.20
Morocco	1	----------	.95

[1] Including samples from Christmas, Curacao, Nauru, and Ocean Islands.

ACID-INSOLUBLE PHOSPHORIC ACID, ALUMINUM, IRON, TITANIUM, CALCIUM, AND MAGNESIUM

Determinations of hydrochloric acid-insoluble phosphoric acid, aluminum, iron, titanium, calcium, and magnesium were made on several samples of the various types of phosphate rock. The insoluble residues were prepared by the procedure of Lundell and Hoffman (*104*), which involves treating 2.5 grams of the rock powder in a platinum dish with 50 cubic centimeters of 1 to 1 hydrochloric acid and digesting on the simmering steam bath for exactly 1 hour. The residue was filtered off, washed with 1 to 20 hydrochloric acid, fused with sodium carbonate and potassium nitrate, and the solution of the melt was analyzed by the methods mentioned previously (p. 17).

The results given in table 22 show that, with a single exception (Florida waste-pond phosphate no. 726), all the samples of domestic phosphate contained insoluble phosphoric acid in amounts ranging from 0.01 percent in Tennessee brown rock no. 587 to 0.13 percent in Idaho rock no. 973. The majority of the samples, however, did not contain more than 0.02 percent, and the average for all samples is 0.03 per cent of insoluble phosphoric acid. Lundell and Hoffman (*104*) state that Bureau of Standards standard sample no. 56 (Tennessee brown-rock phosphate) contains 0.02 to 0.03 percent of phosphoric acid that is insoluble in aqua regia when the sample is digested according to the method of the Association of Official Agricultural Chemists (*6, p. 15*). Determinations on this sample by the authors gave an average of 0.02 percent of phosphoric acid insoluble in aqua regia, which is in exact agreement with the figure obtained for phosphoric acid insoluble in 1 to 1 hydrochloric acid. Similar determinations were not made on the other samples. The state of combination of the acid-insoluble phosphoric acid is not known.

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TABLE 22.—*Hydrochloric acid-insoluble phosphoric acid, aluminum, iron, and titanium in natural phosphates*

Sample no.	Type or source of phosphate	P_2O_5		Al_2O_3		Fe_2O_3		TiO_2	
		Total	Insoluble	Total	Insoluble	Total	Insoluble	Total	Insoluble
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
910	Florida land pebble	31.09	0.02	1.11	0.07	2.39	0.03	0.072	0.035
947	do	31.28	.05	.97	.08	1.69	.00	.064	.026
790	do	31.40	.02	.99	.25	1.62	.00	.06	(1)
439	do	33.22	.02	1.01	.00	1.90	.24	.05	.027
622	do	33.56	.04	.99	.00	.86	.11	.03	.010
912	do	35.37	.05	1.05	.02	.70	.16	.060	.020
771	Florida hard rock	31.25	.02	2.61	.00	1.83	.24	.06	(1)
932	do	35.99	.02	.52	.00	.69	.24	.039	.019
727	Florida waste pond	21.63	.03	13.73	3.73	2.57	.65	.22	(1)
726	do	23.48	.00	11.49	2.03	3.91	.55	.36	(1)
915	do	23.63	.06	16.67	3.48	4.25	.33	.36	.054
1091	Florida soft	25.47	.03	10.49	.93	3.26	.21	.17	.060
580	do	29.49	.03	23.05	.00	3.28	.29	.19	.050
728	do	31.80	.02	5.82	.02	1.54	.05	.11	(1)
443	do	34.94	.02	2.08	.00	.86	.04	.05	.013
587	Tennessee brown rock	30.17	.01	2.72	.59	3.43	.50	.16	.029
[2] 56	do	31.28	.02	3.06	.86	3.30	.85	.08	.035
762	do	33.73	.02	1.78	.05	2.25	.18	.05	(1)
906	do	34.39	.02	1.17	.19	3.42	.53	.05	.024
908	do	34.44	.02	1.16	.40	2.52	.07	.07	.024
772	Tennessee blue rock	30.45	.03	.72	.08	3.54	1.33	.05	(1)
930	do	30.97	.03	1.22	.53	3.42	2.83	.086	.019
[3] 1049	do	31.22	.04	1.19	.36	1.79	1.28	.081	.010
448	do	32.03	.03	.61	.05	3.30	.89	.05	.025
449	do	33.65	.03	.99	.14	2.35	1.78	.06	.016
1048	Tennessee white rock	30.20	.02	1.39	.00	1.75	.23	.075	.02
917	Tennessee phosphatic limestone	11.68	.02	.27	.07	1.95	1.11	.038	.01
550	Idaho, Paris	32.21	.02	1.90	.41	.97	.27	.09	.019
973	Idaho, Conda	32.53	.13	1.16	.27	.87	(1)	.06	(1)
948	Wyoming	30.19	.08	1.19	.42	.87	.57	.10	.008
[4] 904	Connetable Islands	54.51	.69	36.92	2.54	4.43	.09	.16	.16

[1] Not determined.
[2] Bureau of Standards standard sample no. 56.
[3] Kidney phosphate.
[4] Hydrated aluminum phosphate.

In the Florida waste-pond phosphates, Idaho and Wyoming rocks, and some samples of Tennessee brown and blue rocks, a comparatively large portion of the aluminum is insoluble in 1 to 1 hydrochloric acid. On the other hand, Florida land pebble usually contains very little acid-insoluble aluminum, and none was found in two samples of Florida hard rock. The insoluble aluminum is probably present in the form of complex silicates.

Except in two samples of Florida land pebble, acid-insoluble iron was found in all samples analyzed, the amounts ranging from 0.03 to 2.83 percent Fe_2O_3. The presence of pyrite accounts for a large portion of the insoluble iron in Tennessee blue rock and phosphatic limestone and Wyoming rock.

All the samples contained small quantities of acid-insoluble titanium (not more than 0.06 percent TiO_2 in the domestic phosphates).

Analyses of five samples showed the presence of not more than 0.05 percent of insoluble calcium oxide (table 23). The insoluble magnesium content of these samples ranged from 0.06 to 0.13 percent MgO, or approximately 30 to 100 percent of the total magnesium present.

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TABLE 23.—*Hydrochloric acid-insoluble calcium and magnesium in phosphate rock*

Sample no.	Type or source of phosphate	CaO		MgO	
		Total	Insoluble	Total	Insoluble
		Percent	*Percent*	*Percent*	*Percent*
790	Florida land pebble	47.37	0.05	0.14	0.09
771	Florida hard rock	42.52	.05	.21	.06
762	Tennessee brown rock	47.62	.04	.06	.06
772	Tennessee blue rock	44.51	.01	.30	.10
973	Idaho	45.99	.08	.31	.13

COMPOSITION OF BONE ASH

The elements that occur in domestic phosphate rock usually occur also in bone ash. A comparison of the results of analyses (tables 3–6, and 8) indicates that bone ash usually contains higher percentages of magnesium, sodium, copper, zinc, and chlorine, and lower percentages of iron, potassium, titanium, manganese, chromium, vanadium, arsenic, silicon, sulphur, and fluorine than are present in phosphate rock. Aluminum was not found in the particular sample of bone ash analyzed. It should be borne in mind that this sample was a commercial product, and some of the elements found may owe their presence to contamination with foreign materials.

It will be noted that the analysis on bone ash totals only about 99 percent (table 6). This deficiency is attributed to incomplete expulsion of the water at 800° C. The total recovery was not improved by using, instead of the figure for total water and organic carbon, the figure for ignition loss (corrected for carbon dioxide) obtained by heating a sample to constant weight in a muffle furnace at 1,000° C. When, however, a sample was heated to constant weight at 1,250° C. in a tube furnace in a current of air dried by sulphuric acid there was a considerable increase in the ignition loss. Analysis of the ignition residue showed no significant loss of sulphur and alkalies. By using the figure for ignition loss at 1,250° C. the total analysis of the bone ash was increased to 99.89 percent. These results show that a considerable portion of the water in bone ash cannot be driven off at temperatures below about 1,250° C.

COMPOSITION OF MECHANICAL SEPARATES FROM NATURAL PHOSPHATES

With the exception of some of the furnace processes, practically all methods of converting phosphate rock into fertilizer materials and other products involve grinding the rock at some stage of the operation. During recent years, considerable stress has been placed on the importance of the fine grinding of rock that is to be applied directly to the soil as a fertilizer. Inasmuch as phosphate rock is not a homogeneous material it is to be expected that the chemical composition of the ground material will not be the same in particles of different sizes, because of the differences in the hardness and the degree of resistance to grinding exhibited by the various individual components of the rock. Information on the composition of the mechanical fractions, not only of ground phosphate rock but also of the Florida soft and waste-pond phosphates in their natural finely divided condition, is therefore important.

MECHANICAL COMPOSITION OF NATURAL PHOSPHATES

The samples of hard phosphates, except certain samples of Tennessee brown rock which were ground on a commercial scale, were first

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crushed to about 10-mesh size and then ground to pass a 100-mesh sieve having openings 0.147 millimeter square. The grinding was done in a small rotary-disk power mill; the entire sample was run through the mill and the 100-mesh material sieved out, the operation being repeated until the sample was completely reduced to the desired fineness.

The Florida soft and waste-pond phosphates were obtained in the form of comparatively soft lumps, which were crushed to pass a 10-mesh sieve. Grinding during the crushing operation was avoided as much as possible, in order not to break up hard particles that might otherwise fail to disintegrate under the action of water and dispersing agents alone.

The mechanical composition of the samples was determined by the pipette method as modified by Alexander and Jacob (*4*) for the mechanical analysis of finely divided natural phosphates. The ranges of particle size were the same as those customarily used in the mechanical analysis of soils in the United States; namely, (1) particles greater than 50μ in diameter; (2) particles from 50μ to 5μ; and (3) less than 5μ. Following the terminology used in soil analysis, the material comprising these classes will be designated as (1) "sand", (2) "silt", and (3) "clay". It should be noted, however, that these terms are used in this bulletin only for the sake of convenience, and in order to avoid any implication that the chemical composition of the material is similar to that of soil they will always be inclosed in quotation marks.

The results of the mechanical analyses (table 24) show that none of the waste-pond phosphates contained significant quantities of particles coarser than 50μ in diameter. The "sand" fractions, which were separated from the fine material by wet sieving, usually contained considerable organic matter in the form of rootlets and other fibrous vegetative residues. The soft phosphates contained much higher percentages of material coarser than 50μ than were present in the waste-pond phosphates and, as would be expected, the samples showed, in general, considerable differences in their mechanical composition.

TABLE 24.—*Mechanical composition of finely divided natural phosphates as determined by the pipette method of analysis*

Sample no.	Type or source of phosphate [1]	"Sand" >50μ	"Silt" 50μ to 5μ	"Clay" <5μ	"Clay" <2μ
		Percent	*Percent*	*Percent*	*Percent*
725	Florida waste pond	0.3	15.9	83.3	72.3
726	do	.4	11.7	88.1	72.3
727	do	.5	10.1	89.1	78.9
824	do	2.2	15.9	82.6	70.8
825	do	2.2	15.9	81.8	70.6
826	do	1.0	19.5	80.7	69.5
827	do	.2	9.0	91.9	83.0
828	do	.1	12.8	87.0	75.4
915	do	1.7	13.9	84.0	71.9
443	Florida soft	52.1	18.7	29.1	21.4
580	do	40.0	5.2	54.8	54.5
728	do	32.5	15.7	51.3	40.3
910	Florida land pebble	42.1	45.5	12.4	8.2
912	do	35.4	45.5	19.0	13.6
947	do	47.7	42.8	9.4	6.2
932	Florida hard rock	33.2	43.9	22.8	17.7
906	Tennessee brown rock	47.0	37.2	15.7	11.4
908	do	36.7	46.4	16.4	11.4
930	Tennessee blue rock	35.7	54.1	9.2	1.6
973	Idaho	25.6	49.8	24.4	17.7
948	Wyoming	50.1	40.6	8.9	5.3

[1] The soft and waste-pond phosphates were crushed to pass a 10-mesh sieve. The other samples were ground to pass a 100-mesh sieve having openings 0.147 millimeter (147μ) square.

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The mechanical analyses of the ground phosphates show a considerable variation in the distribution of particle size with the different samples, particularly between the "sand" and "clay" fractions. This is owing not only to variations in the physical character of the phosphates themselves but also to the presence of variable quantities of admixed materials, such as quartz and silicates.

Mechanical analyses were also made on four samples of Tennessee brown-rock phosphate, which had been ground to different degrees of fineness as determined by screen analysis. These samples, which were prepared from a regular commercial grade of washed and kiln-dried rock taken from one deposit, were ground experimentally by one of the large phosphate-rock mining companies in a commercial ring-roll type mill equipped with an air-separator. The results of the mechanical analyses by sieving and by the pipette method, which are given in table 25, show that increasing the fineness of phosphate rock from 74.0 percent to 91.5 percent through a 400-mesh sieve does not result in an important increase in the amount of material finer than 5μ in diameter. The principal effect of the finer grinding is to decrease the amount of material coarser than 50μ in diameter.

TABLE 25.—*Mechanical composition of Tennessee brown-rock phosphate ground to different degrees of fineness*

Sieve analysis,[1] material through—				Mechanical analysis by pipette method				
				"Sand"		"Silt" 50μ to 5μ	"Clay"	
100 mesh	200 mesh	300 mesh	400 mesh	>100μ	100μ to 50μ		<5μ	<2μ
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
99.0	91.0	79.3	74.0	2.2	15.3	62.5	19.6	13.2
98.7	94.0	83.5	77.5	1.0	9.9	68.0	20.7	14.2
99.7	98.0	92.1	86.3	.7	6.2	72.2	20.6	14.9
99.8	99.0	95.7	91.5	.3	2.7	71.8	24.8	17.2

[1]Analyses supplied by company furnishing the samples.

PREPARATION OF MECHANICAL SEPARATES

In order to obtain sufficient material for chemical analysis, mechanical separations into "sand," "silt," and "clay" sizes were made on 800-gram samples of the phosphates, prepared as described on pages 57 and 58. The method used for the separations has been described in detail by Alexander and Jacob (*4*), who have also discussed the preparation of the separates used in the present study.

A comparison of the results obtained by the large-scale separations with those obtained by the pipette method of mechanical analysis is given in table 26. In general, the results obtained by the two methods agree very closely. Duplicate determinations by the pipette method do not give results that will check more closely than those obtained on the Florida land-pebble and hard-rock phosphates by the large-scale separations and by the pipette method, respectively. The large-scale separation on waste-pond phosphate no. 726 was not performed so carefully as with the other samples, and quantitative figures were not obtained.

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TABLE 26.—*Comparison of results of large-scale separations with analyses made by the pipette method*

Sample no.	Type or source of phosphate	"Sand", >50μ by —		"Silt", 50μ to 5μ by —		"Clay", <5μ by —		Solution and mechanical losses by —		"Clay" <2μ by pipette method
		Large-scale separation	Pipette method	Large-scale separation	Pipette method	Large-scale separation	Pipette method	Large-scale separation	Pipette method	
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
727	Florida waste pond	0.2	0.5	12.9	10.1	85.3	89.1	1.6	0.3	78.9
915	do	5.1	1.7	19.5	13.9	75.1	84.0	.2	.4	71.9
728	Florida soft	30.4	32.5	20.9	15.7	48.7	51.3	.0	.5	40.3
910	Florida land pebble	41.7	42.1	43.3	45.5	11.8	12.4	[1] 3.2	.0	8.2
912	do	35.1	35.4	45.4	45.5	19.2	19.0	.3	.1	13.6
947	do	48.2	47.7	42.0	42.8	9.6	9.4	.2	.1	6.2
932	Florida hard rock	33.7	33.2	43.8	43.9	22.3	22.8	.2	.1	17.7
906	Tennessee brown rock	46.2	47.0	38.8	37.2	14.0	15.7	1.0	.1	11.4
[2] 908	do	37.6	36.7	46.8	46.4	13.9	16.4	1.7	.5	11.4
[2] 948	Wyoming	49.8	50.1	43.6	40.6	6.6	8.9	.0	.4	5.3
973	Idaho	26.0	25.6	45.5	49.8	27.9	24.4	.6	.2	17.7

[1] A small portion of the "silt" and "clay" was accidentally spilled in this separation.
[2] Lithium oxalate used as a dispersing agent in the large-scale separation.

In addition to the large-scale separations into "sand," "silt," and "clay" fractions, quantities of colloidal material were also extracted from Florida soft and waste-pond phosphates and ground Tennessee brown-rock phosphate by means of the supercentrifuge. For this purpose, the soft and waste-pond phosphates were crushed to pass a 10-mesh sieve. The Tennessee brown rock was a commercially ground material prepared from washed and kiln-dried rock, and had a fineness of approximately 100 percent through a 100-mesh sieve. The method of separating the colloidal material, which has been described by Jacob, Hill, and Holmes (*85*), was the same as that outlined by Gile and coworkers (*55*) for the separation of colloid from soils, except that in no case was it necessary to use a dispersing agent.

As shown in table 27, the amounts of colloidal material obtained from the Tennessee brown rock and the Florida soft and waste-pond phosphates were 11.5, 38.6, and 60.1 percent, respectively. These figures are in fair agreement with the percentages of colloid indicated by the results of mechanical analyses and of water-absorption experiments. The mechanical-analysis figures are those obtained for "clay" finer than 2μ, and may be expected to be somewhat high, since it is hardly probable that all the particles finer than 2μ are colloidal. The size of the colloidal particles extracted from the phosphates was not determined, but, with the method of separation used, it is unlikely that very many, if any, exceeded 1μ in diameter, and the majority were probably 0.3μ and less in diameter. In estimating the percentages of colloid from the results of water-absorption experiments, the equation worked out by Robinson (*161*) for estimating the colloid content of soils has been used. In considering these results it is necessary to assume that the physical properties of the colloidal material in finely divided natural phosphates are similar to those of soil colloids. Unpublished data obtained in this bureau indicate that such an assumption is not far-fetched.

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TABLE 27.—*Colloidal material in finely divided natural phosphates*

Sample no.	Type of phosphate	Colloid content		
		Extracted by means of supercentrifuge	As indicated by—	
			Mechanical analysis	Water absorption
		Percent	*Percent*	*Percent*
[1] 726	Florida waste pond	60.1	72.3	58.4
[2] 728	Florida soft	38.6	40.3	41.3
[3] 762	Tennessee brown rock	11.5	13.4	14.4

[1] 200 grams used for extraction of colloid.
[2] 300 grams used for extraction of colloid.
[3] 1,000 grams used for extraction of colloid.

CHEMICAL COMPOSITION OF SEPARATES

Data on the chemical composition of the mechanical separates are given in tables 28 to 30. In the case of the Florida soft and waste-pond phosphates, the results show that the "silt" fractions contain, as a general rule, higher percentages of calcium, phosphoric acid, and fluorine, and lower percentages of silica, total iron, and aluminum than do either the original materials or the other fractions. The silica tends to concentrate, either in the "sand" fractions as relatively coarse quartz grains, or in the "clay" and colloid fractions as amorphous silica and silicates. The aluminum in the waste-pond phosphates tends to concentrate in the "clay" and colloid fractions, whereas in the soft phosphate it is concentrated to a considerable extent in the "sand" fraction. In general, iron tends to concentrate to a slight extent in the "clay" fractions.

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TABLE 28.—*Chemical composition of "sand", "silt", and "clay" fractions of Florida phosphates*

Sample no.	Mechanical fraction	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3 [1]	TiO_2	CO_2	F	SiO_2 [2]	Insoluble in 1:1 HCl	Ignition loss [3]	$\frac{F}{P_2O_5}$	$\frac{CO_2}{P_2O_5}$
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		
	LAND-PEBBLE PHOSPHATE													
910	Original material	31.09	46.57	0.25	1.11	2.59	0.072	3.76	3.94	6.04	6.56	6.10	0.127	0.121
	"Sand", 147μ to 50μ	30.28	45.19	.23	.76	2.51	.064	3.52	3.70	9.05	9.57	5.74	.122	.116
	"Silt", 50μ to 5μ	32.02	47.64	.26	1.01	2.50	.068	3.65	3.89	4.47	4.90	6.12	.121	.114
	"Clay", <5μ	32.06	46.36	.32	2.23	3.72	.085	3.26	3.91	2.29	2.78	6.80	.122	.102
912	Original material	35.37	49.05	.08	1.05	.70	.060	1.48	3.95	6.34	6.70	2.79	.112	.042
	"Sand", 147μ to 50μ	33.85	47.38	.06	.85	.50	.054	1.45	3.70	11.13	11.52	2.45	.109	.043
	"Silt", 50μ to 5μ	36.01	49.30	.06	.94	.65	.056	1.38	3.82	4.88	5.19	3.02	.106	.038
	"Clay", <5μ	36.10	50.40	.15	1.97	1.00	.062	1.51	3.92	1.84	2.10	3.92	.109	.042
947	Original material	31.28	47.20	.20	.97	1.69	.064	3.70	4.04	6.52	6.74	5.99	.129	.118
	"Sand", 147μ to 50μ	30.97	45.96	.26	.87	1.57	.064	3.57	3.84	9.45	9.72	5.71	.124	.115
	"Silt", 50μ to 5μ	31.93	48.07	.26	.88	1.68	.072	3.74	4.08	4.77	5.03	6.52	.128	.117
	"Clay", <5μ	31.98	47.69	.30	1.60	2.34	.062	3.37	3.84	2.55	2.48	7.08	.120	.105
	HARD-ROCK PHOSPHATE													
932	Original material	35.99	51.08	0.05	0.52	0.69	0.039	2.19	3.91	4.11	4.56	3.07	0.109	0.061
	"Sand", 147μ to 50μ	35.57	50.09	.06	.41	.51	.033	1.93	3.81	7.20	7.74	2.94	.107	.054
	"Silt", 50μ to 5μ	37.09	51.59	.06	.51	.69	.035	2.02	3.88	3.48	3.89	3.35	.105	.054
	"Clay", <5μ	37.13	51.14	.09	1.15	.69	.043	1.92	3.99	.63	1.12	3.88	.107	.052
	SOFT PHOSPHATE													
728	Original material	31.80	41.61	0.22	5.82	1.54	0.11	1.87	3.33	9.80	9.67	5.75	0.105	0.059
	"Sand", >50μ	29.54	31.51	(4)	9.74	1.36	.08	(5)	2.62	18.76	19.23	7.01	.089	----------
	"Silt", 50μ to 5μ	36.33	48.65	(4)	3.40	.83	.09	--------	3.75	2.56	2.71	4.94	.103	----------
	"Clay", <5μ	32.90	44.58	(4)	5.17	1.18	.16	--------	3.18	6.77	7.00	5.44	.097	----------

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WASTE-POND PHOSPHATE

726	Original material	23.48	30.89	0.55	11.49	3.91	0.36	1.70	[6] 2.08	18.10	20.02	7.34	0.089	0.072
	"Sand", >50μ	14.20	([4])	([4])	([4])	([4])	([4])	--------	.51	([4])	([4])	([4])	.036	----------
	"Silt", 50μ to 5μ	29.00	38.76	([4])	7.45	3.04	([4])	--------	[6] 2.76	10.51	([4])	([4])	.095	----------
	"Clay", <5μ	22.01	29.55	([4])	12.85	4.23	([4])	--------	[6] 2.10	19.47	([4])	([4])	.095	----------
727	Original material	21.63	28.70	.84	13.73	2.57	.22	1.00	[6] 1.94	22.94	27.47	6.86	.090	.046
	"Sand", >50μ	16.49	5.72	([4])	10.88	7.42	.17	--------	([4])	16.60	22.30	26.37	----------	----------
	"Silt", 50μ to 5μ	27.05	34.07	([4])	9.65	2.16	.24	--------	[6] 2.40	16.10	18.21	6.01	.089	----------
	"Clay", <5μ	21.09	27.65	([4])	13.56	2.71	.20	--------	[6] 1.97	24.36	29.32	7.13	.093	----------
915	Original material	23.63	25.20	.21	16.67	4.25	.36	1.26	[6] 1.84	16.34	19.40	10.60	.078	.053
	"Sand", >50μ	19.47	21.31	.07	12.22	3.78	.23	--------	[6] 1.53	29.32	39.01	10.73	.079	----------
	"Silt", 50μ to 5μ	27.60	31.10	.01	12.29	3.58	.29	--------	[6] 2.37	12.68	13.82	9.79	.086	----------
	"Clay", <5μ	23.38	24.10	.20	17.12	4.76	.33	--------	[6] 1.73	16.37	19.95	10.81	.074	----------

[1] Total Fe.
[2] Without regard for F.
[3] Constant weight at 1,000° C. after drying at 105°.
[4] Not determined.
[5] Not determined on mechanical fractions of soft and waste-pond phosphates.
[6] Determined by the fusion-acid extraction method (*150*).

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TABLE 29.—*Chemical composition of "sand", "silt", and "clay" fractions of Tennessee, Idaho, and Wyoming phosphates*

Sample no.	Mechanical fraction	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3 [1]	TiO_2	CO_2	F	SiO_2 [2]	Insoluble in 1:1 HCl	Ignition loss [3]	$\frac{F}{P_2O_5}$	$\frac{CO_2}{P_2O_5}$
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		
	TENNESSEE BROWN-ROCK PHOSPHATE													
906	Original material	34.39	47.61	0.10	1.17	3.42	0.05	1.31	3.77	4.86	5.71	3.64	0.110	0.038
	"Sand", 147μ to 50μ	34.77	48.39	(4)	.71	3.11	(4)	.88	3.78	5.56	5.92	2.28	.109	.025
	"Silt", 50μ to 5μ	35.06	48.39	(4)	1.06	3.24	(4)	1.23	3.84	4.20	4.54	2.46	.110	.035
	"Clay", < 5μ	31.69	43.86	(4)	3.79	4.74	(4)	1.13	3.36	6.83	7.65	3.86	.106	.036
908	Original material	34.44	49.19	.02	1.16	2.52	.07	1.96	3.81	4.75	5.46	2.99	.111	.057
	"Sand", 147μ to 50μ	34.49	49.68	.01	.70	2.16	.05	1.39	3.77	5.56	6.02	2.62	.109	.040
	"Silt", 50μ to 5μ	34.85	50.23	.01	.77	2.36	.07	1.50	3.77	4.51	5.04	3.15	.108	.043
	"Clay", < 5μ	32.35	46.27	.06	3.02	3.67	.12	1.27	3.50	5.60	6.96	4.36	.108	.039
	IDAHO PHOSPHATE													
973	Original material	32.53	45.99	0.31	1.16	0.87	0.06	1.72	3.33	6.02	6.86	5.89	0.102	0.053
	"Sand", 147μ to 50μ	35.69	51.25	.01	.17	.16	.03	1.62	3.55	1.65	2.38	5.25	.099	.045
	"Silt", 50μ to 5μ	32.96	45.13	.02	.63	.40	.08	1.59	3.49	7.67	8.48	5.36	.106	.048
	"Clay", < 5μ	28.60	39.20	.17	3.09	2.04	.15	.86	3.01	9.69	12.40	8.55	.105	.030
	WYOMING PHOSPHATE													
948	Original material	30.19	46.22	0.08	1.19	0.87	0.10	4.13	3.54	5.69	7.54	6.78	0.117	0.137
	"Sand", 147μ to 50μ	33.41	49.41	.09	.46	.46	.06	3.35	3.62	3.11	3.96	5.81	.108	.100
	"Silt", 50μ to 5μ	26.73	42.81	.08	1.50	1.11	.14	3.41	3.29	9.56	11.77	5.83	.123	.128
	"Clay", < 5μ	23.67	37.28	.15	4.47	2.22	.15	1.05	2.93	9.76	14.08	15.22	.124	.044

[1] Total Fe.
[2] Without regard for F.
[3] Constant weight at 1,000° C. after drying at 105° C.
[4] Not determined.

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TABLE 30.—*Chemical composition of colloidal material extracted from natural phosphates*

Sample analyzed	P_2O_5	CaO	MgO	Al_2O_3	Fe_2O_3 [1]	TiO_2	Na_2O	K_2O	MnO	Cr_2O_3	V_2O_3	SiO_2 [2]	CO_2	F	Cl	SO_3 [3]	Ignition loss [4]	Total	
																		Uncorrected	Corrected [5]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
FLORIDA SOFT PHOSPHATE NO. 728																			
Original material	31.80	41.61	0.22	5.82	1.54	0.11	0.26	0.14	0.014	0.018	0.00	10.67	1.87	3.33	Trace.	0.17	5.75	103.32	100.05
Colloid	31.43	41.76	.30	6.37	1.60	.23	.13	.30	.023	.016	(6)	10.60	1.74	[7] 2.99	(6)	.01	5.81	103.31	100.31
FLORIDA WASTE-POND PHOSPHATE NO. 726																			
Original material	23.48	30.89	0.55	11.49	3.91	0.36	0.20	0.47	0.022	0.028	0.02	19.78	1.70	[7] 2.08	0.005	0.14	7.34	102.47	99.89
Colloid	18.12	23.73	.70	15.87	5.12	.53	.12	.65	.048	.038	(6)	26.20	.97	[7] 1.61	(6)	.01	8.35	102.07	100.42
TENNESSEE BROWN-ROCK PHOSPHATE NO. 762																			
Original material	33.73	47.62	0.06	1.78	2.25	0.05	0.14	0.31	0.27	0.007	0.00	7.49	1.71	3.87	0.005	0.81	3.03	103.13	99.79
Colloid	25.02	33.68	.05	9.97	4.57	.23	.31	1.19	.57	.010	.00	16.48	1.17	[7] 2.64	(6)	.10	6.96	102.95	100.67

[1] Total Fe.
[2] Total Si.
[3] Total sulphur.
[4] Constant weight at 1,000° C. after drying at 105° C.
[5] Corrected for CO_2 and O equivalent of F and Cl.
[6] Not determined.
[7] Determined by fusion-acid extraction method (*150*).

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The data given in table 28 show that the silica in the ground Florida land-pebble and hard-rock phosphates concentrates to a marked extent in the "sand" fractions, and that there is a progressive and significant decrease in the percentage of silica as the particle size decreases. This is undoubtedly because of the presence of considerable quantities of quartz, which, in comparison with the phosphate, is relatively difficult to grind. In general, iron and aluminum tend to concentrate in the "clay" fractions, whereas calcium and phosphoric acid concentrate to a small extent in the "silt" and "clay" fractions.

Contrary to the results obtained on the Florida phosphates, there is no very considerable variation in the silica content of the "sand," "silt," and "clay" fractions separated from the Tennessee brown-rock phosphates (table 29), although the silica tends to concentrate somewhat in the "sand" and "clay" fractions. On the other hand, silica concentrated to a very marked extent in the colloid fraction of no. 762 (table 30). The percentages of iron and aluminum in the fractions increase with decrease in particle size, the aluminum, in particular, concentrating to a marked extent in the "clay" and colloid fractions. Calcium and phosphoric acid tend to concentrate to a slight extent in the "silt" fractions, whereas the "clay" fractions contain decidedly smaller percentages. There was a very marked decrease in the percentages of calcium and phosphoric acid in the colloid fraction as compared with those in the original material.

In the Idaho and Wyoming phosphates (table 29) the percentages of silica, iron, and aluminum increase considerably as the particle size decreases, the iron and aluminum concentrating particularly in the "clay" fractions. The percentages of calcium and phosphoric acid decrease to a significant extent with decrease in particle size.

As a general rule, the fluorine-phosphoric acid ratios are approximately constant in the mechanical fractions of a particular sample and are close to the ratio in the original phosphate. There is some variation from this rule in certain of the soft and waste-pond phosphates. This is probably because of the presence of aluminum phosphate in these samples (p. 75).

There is, in general, a fair degree of constancy in the carbon dioxide-phosphoric acid ratios in the mechanical fractions of a particular sample. It will be noted, however, that the ratios in the fractions are almost invariably lower than the ratio in the original phosphate. Inasmuch as large volumes of water were used in making the mechanical separations, it is probable that the lower ratios in the mechanical fractions are caused, at least in part, by the dissolution of calcium carbonate during the process of separation.

AMMONIUM CITRATE- AND CITRIC ACID-SOLUBLE PHOSPHORIC ACID IN NATURAL PHOSPHATES

In fertilizer-control work in the United States, the neutral ammonium citrate method is used for the laboratory determination of available phosphoric acid in all phosphates and phosphatic fertilizers except basic slag, which is evaluated by the 2 percent citric acid method. Although the direct use of ground phosphate rock as a fertilizer is limited, in the United States, to about 30,000 to 40,000 tons annually, principally Tennessee brown rock, comparative data on the solubilities of the different types of domestic phosphates in neutral ammonium

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citrate and 2 percent citric acid solutions are, nevertheless, of general interest.

Citric acid-soluble phosphoric acid was determined by the method of the Association of Official Agricultural Chemists (*6, p. 27*), as devised for the evaluation of basic slag. Ammonium citrate-soluble phosphoric acid was determined by the former official method (*6, p. 17*), using 2-gram samples and digesting with 100 cubic centimeters of neutral ammonium citrate solution for 0.5 hour at 65° C. Shortly after this study was completed the official method for citrate-soluble phosphoric acid was changed to specify the use of 1-gram samples and the time of digestion was increased from 0.5 to 1 hour (*89; 98, p. 66; 166; 167*). The modified method when applied to such materials as dicalcium and tricalcium phosphates and raw, steamed, and naphtha-extracted bones (*84, 86, 87, 167*) gives significantly higher percentages of citrate-soluble phosphoric acid than does the old procedure, but with mineral phosphates and bone ash the results by the two procedures do not differ greatly. For example, with several samples of phosphate rock, apatite, and bone ash, the average increase in citrate-soluble phosphoric acid obtained by the modified method amounted to only 0.97 percent on the sample, or 2.3 percent on the total phosphoric acid. Although this increase is insignificant, the effect of the change in the method should be borne in mind in connection with the results for citrate-soluble phosphoric acid given in this publication.

All samples used in the ammonium citrate- and citric acid-solubility determinations were ground to pass a 100-mesh sieve. The ammonium citrate extracts were filtered by means of short Pasteur-Chamberland tubes (grade F), in order to obtain clear filtrates, since cloudy filtrates were usually obtained when the extracts were filtered through papers, even those of the closest texture. Neutral ammonium citrate solution was prepared by the official method (*6, p. 17*), using phenol red as an indicator, the pH values of the several solutions used during the course of this work ranging from 6.9 to 7 as determined potentiometrically by means of the hydrogen electrode.

The results of analyses (tables 31 and 32) indicate that the citrate-soluble phosphoric acid content of the domestic commercial types of phosphate rock ranges from about 0.3 to 2.5 percent on the sample or about 1 to 8 percent on the total phosphoric acid. Despite the fineness of the individual particles, Florida waste-pond phosphates contain, in general, smaller percentages of citrate-soluble phosphoric acid than do any of the domestic phosphate rocks, except the rock from Cokeville, Wyo. The Florida land-pebble and hard-rock and the South Carolina phosphates average highest in citrate-soluble phosphoric acid, followed in descending order by the Tennessee white-rock, Florida soft, Idaho, Montana, Tennessee blue-rock and brown-rock, Florida waste-pond, and Wyoming phosphates. The lower grades of Florida land pebble contain, in general, somewhat larger quantities of citrate-soluble phosphoric acid than do the higher grades, whereas the reverse is true with the Tennessee brown rock. In the other types of phosphate, there seems to be no definite relation between the grade of the rock and its citrate-soluble phosphoric acid content. As compared with the phosphate rocks in general, fluorapatite is very low in citrate-soluble phosphoric acid.

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TABLE 31.—*Ammonium citrate- and citric acid-soluble phosphoric acid in Florida phosphates*

Sample no.	Total P_2O_5	Citrate-soluble P_2O_5 [1]	Citric acid-soluble P_2O_5 [2]
	Percent	*Percent*	*Percent*
LAND-PEBBLE PHOSPHATE			
618	30.53	2.53	6.53
617	30.70	2.56	6.14
619	30.98	2.45	6.55
910	31.09	1.55	7.17
947	31.28	1.71	6.59
790	31.40	2.25	6.77
439	33.22	2.42	6.68
622	33.56	1.60	6.38
627	33.70	1.62	6.08
912	35.37	.77	6.67
898	35.55	1.18	6.25
Average	32.49	1.88	6.53
HARD-ROCK PHOSPHATE			
771	31.25	2.13	6.87
589	34.68	.90	6.40
434	35.33	2.00	6.50
932	35.99	1.89	7.23
Average	34.31	1.73	6.75
SOFT PHOSPHATE			
1091	25.47	2.11	8.02
580	29.49	.79	5.82
728	31.80	1.50	7.12
443	34.94	1.94	7.26
Average	30.43	1.59	7.06
WASTE-POND PHOSPHATE			
826	15.34	0.09	1.21
828	19.83	.64	7.99
727	21.63	.75	6.35
827	22.20	.37	7.28
726	23.48	.97	7.12
825	23.48	.18	7.16
915	23.63	.34	7.50
824	24.24	.56	7.24
725	25.31	1.34	6.88
Average	22.14	.58	6.53

[1] 2-gram samples digested for 30 minutes at 65° C. with 100 cubic centimeters of neutral ammonium citrate solution.
[2] 2-gram samples shaken for 30 minutes with 200 cubic centimeters of 2 percent citric acid solution.

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TABLE 32.—*Ammonium citrate- and citric acid-soluble phosphoric acid in Tennessee and other phosphates*

Sample no.	Type or source of phosphate	Total P_2O_5	Citrate-soluble P_2O_5 [1]	Citric acid-soluble P_2O_5 [2]
		Percent	*Percent*	*Percent*
587	Tennessee brown rock	30.17	0.80	5.84
[3] 56	do	31.28	.77	5.74
564	do	32.85	.84	5.90
762	do	33.73	1.19	5.88
906	do	34.39	1.20	5.67
903	do	34.44	1.14	6.25
Average		32.81	.99	5.88
772	Tennessee blue rock	30.45	1.83	4.75
930	do	30.97	1.26	6.90
1049	do	31.22	.54	5.42
448	do	32.03	1.00	6.43
449	do	33.65	1.15	6.98
Average		31.66	1.16	6.10
1048	Tennessee white rock	30.20	1.64	5.94
1031	do	35.80	1.79	7.35
Average		33.00	1.71	6.64
1139	South Carolina land rock	26.92	2.51	7.83
1138	do	27.85	2.43	8.05
Average		27.38	2.47	7.94
550	Idaho	32.21	1.21	8.16
454	do	32.24	.87	5.95
973	do	32.53	1.56	6.05
Average		32.33	1.21	6.72
1009	Montana	31.39	1.02	4.87
1010	do	37.47	1.35	5.54
Average		34.43	1.18	5.20
948	Wyoming	30.19	.33	4.15
1162	Morocco	35.11	2.75	11.25
552	Tunis, Gafsa	27.55	2.21	10.08
985	Curacao Island	38.59	2.92	13.74
905	Fluorapatite	40.30	.67	2.18
971	Bone ash	40.36	3.31	11.29
[4] 904	Connetable Islands	54.51	3.36	.32

[1] 2-gram samples digested for 30 minutes at 65° C. with 100 cubic centimeters of neutral ammonium citrate solution.
[2] 2-gram samples shaken for 30 minutes with 200 cubic centimeters of 2 percent citric acid solution.
[3] Bureau of Standards standard sample no. 56.
[4] Hydrated aluminum phosphate.

The percentages of citric acid-soluble phosphoric acid in the various types of phosphate rock tend, as a general rule, to run parallel to the percentages of citrate-soluble phosphoric acid. The results (tables 31 and 32) indicate that the citric acid-soluble phosphoric acid content of the domestic rocks ranges from about 4 to 8 percent on the sample, or 14 to 29 percent on the total phosphoric acid. The Florida soft and waste-pond phosphates contain, in general, somewhat higher percentages of citric acid-soluble phosphoric acid than are found in the majority of samples of hard phosphates. It will be noted that the Curacao Island, Morocco, and Tunis phosphates are more soluble and fluorapatite is less soluble in 2 percent citric acid than are any of the domestic rocks. The aluminum phosphate from the Connetable Islands is practically insoluble in citric acid. Unlike the calcium phosphates, the phosphates of iron and aluminum are more soluble

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in neutral ammonium citrate solution than in 2 percent citric acid (*87*). Numerous results on the solubility of phosphates in citric acid solutions have appeared in the literature during the past 17 years (*2*, *3*, *87*, *157*, *159*).

The data in table 33 show that the percentages of ammonium citrate- and of citric acid-soluble phosphoric acid in the mechanical fractions of the ground phosphate rocks increase with decrease in particle size. In ammonium citrate-soluble phosphoric acid, the average increase in going from the "sand" to the "clay" fractions amounted to 1.58 percent on the sample, or 4.9 percent on the total phosphoric acid. In citric acid-soluble phosphoric acid, the average increase amounted to 1.91 percent on the sample, or 7.2 percent on the total phosphoric acid. The low ammonium citrate solubility of the phosphoric acid in the original sample of Wyoming phosphate follows through into the mechanical fractions. The percentages of ammonium citrate- and citric acid-soluble phosphoric acid in the Florida soft and waste-pond phosphates show no regular changes with decrease in particle size. The phosphoric acid in the "clay" fractions of these materials is, in general, less soluble in citrate solution than is the phosphoric acid in the "clay" fractions of the ground phosphate rocks.

TABLE 33.—*Effect of particle size on the solubility of natural phosphates in ammonium citrate and citric acid solutions*

Sample no.	Mechanical fraction	Total P_2O_5	Citrate-soluble P_2O_5 [1]	Citric acid-soluble P_2O_5 [2]
		Percent	*Percent*	*Percent*
	FLORIDA LAND-PEBBLE PHOSPHATE			
910	Original material	31.09	1.55	7.17
	"Sand"	30.28	.35	6.56
	"Silt"	32.02	1.71	7.27
	"Clay"	32.06	2.60	8.80
912	Original material	35.37	.77	6.67
	"Sand"	33.85	.51	6.21
	"Silt"	36.01	.60	6.71
	"Clay"	36.10	1.14	7.46
947	Original material	31.28	1.71	6.59
	"Sand"	30.97	.50	5.81
	"Silt"	31.93	1.51	6.87
	"Clay"	31.98	2.57	8.59
	FLORIDA HARD-ROCK PHOSPHATE			
932	Original material	35.99	1.89	7.23
	"Sand"	35.57	.98	6.12
	"Silt"	37.09	1.87	6.93
	"Clay"	37.13	2.41	8.20
	FLORIDA SOFT PHOSPHATE			
728	Original material	31.80	1.50	7.12
	"Sand"	29.54	1.13	6.36
	"Silt"	36.33	.72	7.84
	"Clay"	32.90	.96	7.84
	Colloid	31.43	.68	7.66

[1] 2-gram samples digested for 30 minutes at 65° C. with 100 cubic centimeters of neutral ammonium citrate solution.
[2] 2-gram samples shaken for 30 minutes with 200 cubic centimeters of 2 percent citric acid solution.

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TABLE 33.—*Effect of particle size on the solubility of natural phosphates in ammonium citrate and citric acid solutions*—Continued

FLORIDA WASTE-POND PHOSPHATE

Sample no.	Mechanical fraction	Total P_2O_5	Citrate-soluble P_2O_5	Citric acid-soluble P_2O_5
		Percent	*Percent*	*Percent*
726	Original material	23.48	0.97	7.12
	"Sand"	14.20	1.57	(3)
	"Silt"	29.00	1.81	6.74
	"Clay"	22.01	1.65	7.30
	Colloid	18.12	.87	7.20
[4] 727	Original material	21.63	.75	6.35
	"Silt"	27.05	.45	6.80
	"Clay"	21.09	.66	7.45
915	Original material	23.63	.34	7.50
	"Sand"	19.47	.48	7.25
	"Silt"	27.60	.11	7.08
	"Clay"	23.38	.88	7.52

TENNESSEE BROWN-ROCK PHOSPHATE

762	Original material	33.73	1.19	5.88
	Colloid	25.02	2.06	7.70
906	Original material	34.39	1.20	5.67
	"Sand"	34.77	.69	5.57
	"Silt"	35.06	1.28	6.07
	"Clay"	31.69	2.04	6.97
908	Original material	34.44	1.14	6.25
	"Sand"	34.49	.26	5.95
	"Silt"	34.85	.97	6.64
	"Clay"	32.35	1.62	7.79

IDAHO PHOSPHATE

973	Original material	32.53	1.56	6.05
	"Sand"	35.69	.13	5.87
	"Silt"	32.96	1.09	6.45
	"Clay"	28.60	2.63	7.31

WYOMING PHOSPHATE

948	Original material	30.19	0.33	4.15
	"Sand"	33.41	.16	4.14
	"Silt"	26.73	.06	4.82
	"Clay"	23.67	.91	6.42

[3] Not determined. [4] Insufficient quantity of "sand" fraction for analysis.

COMPOUNDS PRESENT IN PHOSPHATE ROCK

The compounds present in phosphate rock may be divided into two classes, phosphatic and nonphosphatic or admixed materials. Identification of all the compounds comprised in these classes remains to be accomplished, but progress in this direction has been made by means of careful studies of the combined results of microscopical, X-ray diffraction, and chemical examinations.

Numerous difficulties arise when these methods of attack are applied individually to such a material as phosphate rock. Microscopical examination is of great value in the identification of minute quantities of crystalline substances, but the very fine particle size of most of the compounds in phosphate rock limits the applicability of this method. X-ray diffraction photographs are of some value in the identification of impurities present in amounts greater than about 2 percent,

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but they are of far greater value in characterizing the principal constituent in the material under examination. However, several phosphate compounds that may be present in phosphate rock have very similar structures and give almost identical diffraction photographs. Furthermore, these compounds seem to be able to form a rather extensive series of solid solutions. Therefore, extreme care must be exercised in interpreting the photographs. Chemical analysis is of value in determining the amounts of the various elements and certain of the radicals in phosphate rock, but it is not possible from such results alone to distribute correctly these elements and radicals among the compounds that may be present, for example, to distribute fluorine and carbon dioxide among the phosphate minerals and possible fluoride and carbonate impurities.

PHOSPHATIC COMPOUNDS

Except in rare instances, the calcium phosphates present in phosphate rock have complicated structures, which, in general, may be represented by the type formula $3Ca_3(PO_4)_2.CaX$, or $Ca_{10}X(PO_4)_6$, where X may be one or more negative radicals such as halogens, carbonate, hydroxyl, etc. Fluorapatite, $Ca_{10}F_2(PO_4)_6$, is the best-known crystalline representative of such compounds. Other compounds of this type, which are known to exist in nature or have been prepared in the laboratory, are hydroxyapatite, $Ca_{10}(OH)_2(PO_4)_6$; chlorapatite, $Ca_{10}Cl_2(PO_4)_6$; and carbonate apatite, $Ca_{10}(CO_3)(PO_4)_6$, which probably carries one molecule of water. Owing to the similarity in their crystal structures as shown by X-ray diffraction studies (*64*, *65*), the formation of solid solutions among these compounds is to be expected. The presence of solid solutions would explain, in a large measure, the variable compositions of many of the poorly defined minerals described as occurring in phosphate rock (*39*, *p. 768; 78*).

The possibility of the presence of significant quantities of chlorapatite in the domestic phosphate rocks is eliminated by the fact that these materials usually contain less than 0.02 percent of chlorine.

The universal presence of comparatively large percentages of fluorine in phosphate rocks, particularly those from the continental deposits, led more than 40 years ago to the conclusion that phosphate rock is essentially fluorapatite (*101*). This conclusion is supported by the recent X-ray diffraction studies of Hendricks and coworkers (*64*). The results of these studies show that fluorapatite is the predominating constituent of all the commercial varieties and grades of phosphate rock produced in the United States. On the other hand, X-ray analysis indicates that hydroxyfluorapatite, $Ca_{10}(OH, F)_2(PO_4)_6$, is an important constituent of the Nauru, Christmas, and Ocean Island phosphates. So far as is known to the authors, fluorapatite is the only coarsely crystalline calcium phosphate mineral that has been identified with certainty in the commercial types of domestic phosphate rock by means of the microscope, and this only in rare instances. In the present investigation, macrocrystalline fluorapatite was found in only two samples, namely, no. 1011 (table 5) from Garrison, Mont., and no. 910 (table 3) from Mulberry, Fla.

Chemical analyses (tables 9–12) show that the domestic types of phosphate rock, excluding the Florida soft and waste-pond phosphates, usually contain about 20 to 35 percent more fluorine than is theoretically required to combine with the phosphate for the formation of

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fluorapatite, the excess running as high as about 55 percent in Oklahoma phosphate and in certain samples of Florida land pebble and South Carolina land rock. Satisfactory proof of the exact state of combination of this excess fluorine has not been obtained. Microscopical examination showed the presence of coarsely crystalline calcium fluoride (fluorite) in only two samples (nos. 1011 and 1012, table 11), which were exceptionally high in fluorine. The X-ray diffraction photographs also showed the presence of calcium fluoride in these samples, whereas they gave no indication of its presence in other samples. Fluorite has previously been identified in phosphate rock from western United States (*51; 119, p. 213*) and Palestine (*5*).

According to Bredig and coworkers (*14*), fluorapatite can take into its lattice excess calcium fluoride to the extent of approximately 70 percent of that theoretically required by the formula $Ca_{10}F_2(PO_4)_6$ without causing more than a very slight broadening of the lattice. The same authors offer this as an explanation of the presence of the excess fluorine usually found in continental phosphate rocks and frequently in coarsely crystalline fluorapatite. Although further work in this direction is needed, it should be pointed out that, with the exception of the samples in which the presence of fluorite was detected, none of the domestic phosphates analyzed in this investigation contained more fluorine than corresponds to an excess of 70 percent over that required to form fluorapatite with all the phosphoric acid present. The excess fluorine in several samples of Russian phosphate (table 13), which were not examined microscopically for the presence of fluorite, slightly exceeded this figure.

Conclusive evidence of the presence of carbonate apatite, $Ca_{10}(CO_3)(H_2O)(PO_4)_6$, in domestic phosphate rock has not been obtained. This compound, which seems to be the essential phosphatic component of fresh bone (*64, 65, 164*), is probably a constituent of certain insular phosphate rocks, but X-ray data indicate that there is no great displacement of fluorine by either carbonate or hydroxyl groups in the apatite mineral that is predominant in domestic rock (*64*). Microscopical examination of phosphate rock usually shows the presence of calcite, often in sufficient quantity to account for all the carbon dioxide. Hendricks and coworkers (*64*) have pointed out, however, that in some samples, particularly certain of the Florida land-pebble phosphates, the amount of calcite is markedly lower than is indicated by the carbon dioxide content. In such samples, the X-ray data also indicate that crystalline calcium carbonate is not present in amounts greater than about 2 percent. These samples do not contain sufficient magnesium carbonate to account for the discrepancy. It is possible that the excess carbon dioxide is present as very finely divided calcium carbonate in quantities too small to be determined by microscopical and X-ray analyses. It is also possible that at least a part of this carbon dioxide is present in the form of carbonate apatite or of solid solutions of carbonate apatite and other apatites. Finally, there is the possibility that carbon dioxide has gone into the fluorapatite lattice as calcium carbonate in the manner postulated by Bredig and coworkers (*14*) to explain the presence of excess fluorine in phosphate rock. In this connection, it should be noted that coarsely crystalline fluorapatite very frequently contains significant quantities of carbon dioxide (*39, p. 765*).

The properties of the submicrocrystalline carbonate present in phosphate rock are somewhat different from those of coarsely crystal-

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line calcite. For example, it has recently been pointed out (*74*) that complete removal of the carbon dioxide by heating at high temperatures is more difficult with phosphate rock than with either dolomite or high-calcium limestone. Schucht (*172, p. 311*) and Gale and Richards (*51*) state that certain samples of Florida and Utah phosphates contain carbon dioxide which is not liberated on treatment of the rock powder with cold dilute acetic, phosphoric, or hydrochloric acid, but comes off when the sample is treated with hot dilute phosphoric or hydrochloric acid. Since calcite is completely decomposed by dilute acetic acid, these authors suggest that the difficultly soluble carbonate may be present as a carbonate phosphate.

The results of experimental work on the purification of phosphate rock by the flotation process indicate that coarsely crystalline calcite may be readily removed by this method, whereas the remainder of the carbonate is removed only in part, if at all, even though the rock be ground to a fineness of 200 mesh.[12] This behavior may be due either to carbonate apatite or to calcium carbonate in the fluorapatite lattice, or to the presence of free calcium carbonate so thoroughly disseminated throughout the phosphate particles that separation by flotation is impossible unless the rock be ground extremely fine. While these observations do not prove the presence of carbonate apatite, they show that at least a part of the carbonate manifests properties unlike those of calcite.

As further evidence of the presence of carbonate phosphates in phosphate rock, Matson (*122, p. 86*) has reported that Florida phosphates contain a mineral having optical properties corresponding to those of francolite or staffelite, $3Ca_3(PO_4)_2.CaCO_3.CaF_2.H_2O$ (*95*; *96*; *169, p. 89–100*). Correlating the results of his microscopical examination with the chemical analyses reported by other investigators, Matson suggests that the Florida phosphates are mixtures of francolite and fluocollophanite, $3Ca_3(PO_4)_2.Ca(F_2,CO_3).H_2O+nH_2O$. Aside from the optical data, this suggestion is based largely upon the molecular ratios of total calcium oxide, phosphoric acid, carbon dioxide, and fluorine calculated from the chemical analyses. It should be pointed out, however, that the fluorine figures on the majority of the samples were unquestionably much too low, and that Matson failed to take into consideration the fact that in most samples a portion of the carbon dioxide is undoubtedly present in the form of calcite (*64*).

As in the case of carbonate apatite, there is no direct evidence of the presence in domestic phosphate rock of hydroxyapatite, either as the individual compound or as solid solutions with other apatites. The microscopical and X-ray diffraction examinations do not throw any light on this subject, but the chemical analyses (tables 3–6 and 17) indicate that many samples may contain small quantities of calcium in combination with the hydroxyl group.

Thus, most phosphate rocks contain appreciable amounts of calcium in excess of that required to combine with the fluorine, carbon dioxide, and the acid-soluble sulphate radical, and with the phosphoric acid in the ratio required by the calcium phosphate portion of the apatite formula. For example, the excess calcium in the samples of Christmas Island, Nauru, and Ocean Island phosphates (table 6) ranges from 2.53 to 3.73 percent CaO. The X-ray data indicate that

[12] Private communication from Charles E. Heinrichs, of the Phosphate Recovery Corporation.

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these phosphates contain hydroxyfluorapatite (*64*). Likewise, in 15 samples of various types of domestic phosphates the excess calcium ranged from 0.22 to 2.11 percent CaO, the average being 0.95 percent. It is hardly possible that analytical errors, which accumulate in the results for excess calcium, can account for the rather large values obtained in many cases. The presence of dicalcium phosphate and of phosphoric acid, fluorine, carbon dioxide, or sulphuric acid in combination with elements other than calcium would only serve to increase the excess of calcium. Except for the presence of insignificant quantities of acid-insoluble calcium (table 23), there is no direct evidence that calcium occurs in domestic phosphate rock in combination with acid radicals other than those mentioned, although Schucht (*172, p. 74*) states that calcium silicate occurs in Algerian and Belgian phosphates. On the basis of the information available at present, it does not seem unreasonable to postulate the existence of at least a portion of the excess calcium in the form of hydroxyapatite, or solid solutions of this compound with other apatites, or as calcium hydroxide within the lattice of fluorapatite.

There is no evidence that dicalcium and tricalcium phosphates occur in any of the varieties of domestic phosphates. Hendricks and coworkers (*64*) have shown, however, that Curacao Island phosphate contains a compound which gives the same X-ray diffraction pattern as does anhydrous tricalcium phosphate. Dicalcium phosphate has been reported to occur in isolated masses on the islands of Moneta and Mona, West Indies (*39, p. 784*).

Microscopical examination has not revealed the presence of iron or aluminum phosphates in the samples used in this investigation. The occurrence of vivianite, $Fe_3(PO_4)_2.8H_2O$, has been noted in several localities in the Florida land-pebble district (*122, p. 85*), particularly in a phosphate rock deposit near Plant City (*203*). Larsen and Shannon (*100*) reported the presence of complex phosphate minerals containing calcium, aluminum, and, in some cases, sodium in a deposit near Fairfield, Utah. Mineralogical evidence of the presence of these or of any other iron and aluminum phosphates in the commercial grades of domestic rock has not come to the attention of the authors. The results of chemical analyses, however, give evidence of the presence of iron or aluminum, probably the latter, combined with phosphoric acid in certain samples of the Florida soft and waste-pond phosphates.

Thus, the soft phosphates nos. 580 and 1091, and the waste-pond phosphate no. 915 (table 3) contain less calcium (2.92 to 19.12 percent CaO on the samples) than is required to combine with the fluorine and carbon dioxide and with the phosphoric acid in the ratio required by the calcium phosphate portion of the fluorapatite formula. In soft phosphate no. 580, the marked deficiency of calcium (19.12 percent CaO) together with the high alumina (23.05 percent) and the low total iron (3.28 percent Fe_2O_3) gives conclusive evidence of the presence of considerable aluminum phosphate. A deficiency of calcium also occurs in the "sand" fractions of soft phosphate no. 728 and waste-pond phosphate no. 727 (table 28). Since the original samples of these materials are not deficient in lime, it may be concluded that concentration of the iron or aluminum phosphate has occurred in the "sand" fractions. Similar calculations on the original

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samples and the mechanical fractions of the other types of domestic phosphates give no indication of the presence of iron or aluminum phosphates.

NONPHOSPHATIC COMPOUNDS

The occasional occurrence of fluorite and the frequent occurrence of calcite in phosphate rock have been pointed out on page 73.

Microscopical examination usually indicates the presence of gypsum (*64*) in sufficient quantity to account for the acid-soluble sulphate in domestic phosphate rocks (table 17). Gale and Richards (*51*) reported the presence of both gypsum and anhydrite in low-grade phosphate from the Crawford Mountains, Utah. The acid-insoluble sulphide, found in significant quantities in Tennessee blue rock and phosphatic limestone, South Carolina land rock, rock from Cokeville, Wyo., and in one sample of Tennessee brown rock (table 17), is present principally in the form of pyrite (FeS_2). All samples of phosphate examined during this investigation also contained organic sulphur, the quantities running as high as 0.8 percent SO_3 in rock from Conda, Idaho.

The state of combination of the iron may vary considerably in different varieties of phosphate. As pointed out in the preceding paragraph, pyrite is an important constituent of several of the domestic types of rock. Analysis of the organic material isolated from several samples also indicates that iron may be present in organic combination (table 20). According to Matson (*122, p. 84*), limonite, $2Fe_2O_3.3H_2O$, is the most common iron-bearing mineral in the Florida phosphate deposits, though glauconite is a constituent of the "bedrock" in the pebble-phosphate region. Matson also states that in many of the deposits iron probably occurs in the form of ferrous silicate at depths where oxidation has not been very effective. The color of Tennessee brown rock and of Conda, Idaho, rock indicates the presence of ferric oxide.

Aside from that occurring as the phosphate, the greater part of the aluminum is probably present in the form of silicates, principally in the submicrocrystalline condition. Microscopical examination of Florida land-pebble phosphate no. 790 by W. H. Fry, of the soil chemistry and physics division of the Bureau of Chemistry and Soils, showed the presence of very small quantities of orthoclase and microcline. Traces of plagioclase were found in Florida land-pebble phosphates nos. 910, 912, and 947, and no. 912 contained very small quantities of muscovite and tourmaline. Mica was identified in Florida hard-rock phosphate no. 771. Coarsely crystalline silicates were not found in samples of the other types of rock. Gale and Richards (*51*) reported the presence of kaolin in samples of phosphate from Idaho, Utah, and Wyoming, and Matson (*122, p. 84*) stated that kaolin is the most prominent aluminum-bearing mineral in the Florida phosphates.

The nature of the compound or compounds accounting for the presence of sodium and potassium in natural phosphates has not been definitely established. The studies of Hausen (*59*) and Borgström (*10*) indicate that at least a portion of the sodium may have replaced calcium in the complex apatitelike compounds which are the principal phosphatic components of natural calcium phosphates. As pointed

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out by Hendricks and coworkers (*64*), a partial replacement of calcium by sodium is structurally possible because the ionic radii of sodium and calcium are nearly the same. On the other hand, there is a considerable difference in the sizes of the potassium and calcium ions and, consequently, replacement of calcium by potassium in the apatite complex would seem to be improbable. Alkali aluminum silicates account, no doubt, for at least a portion of the sodium and potassium present in many phosphate rocks.

Matson (*122, p. 85*) suggests that the magnesium in the Florida phosphates probably occurs most commonly as magnesite. Results obtained on samples of Florida, Tennessee, and Idaho phosphates (table 23) show, however, that approximately 30 to 100 percent of the total magnesium is insoluble in hot 1 to 1 hydrochloric acid. This indicates the presence of magnesium-bearing silicates.

Quartz is a common constituent of all types of phosphate rock. Most types also contain silica in the form of silicates.

Not enough information is available to justify conclusions as to the states of combination of the small quantities of titanium, manganese, chromium, vanadium, copper, zinc, and arsenic that are present in nearly all types of phosphate rock.

SUMMARY

A brief review of the phosphate deposits and the production and reserves of phosphate rock in the United States is given. The flotation process of concentrating low-grade phosphate ores is discussed with reference to its value in the conservation of the phosphate deposits in the southeastern part of the United States.

The results of an analytical study of 46 samples of mineral calcium phosphates representing nearly all of the more important domestic types and sources of this material are presented. Data are also given on the composition of 11 samples of bone ash, apatites, and foreign phosphate rocks, and on the percentages of fluorine and phosphoric acid in a large number of additional samples from deposits throughout the world.

Phosphoric acid, lime, alumina, iron, silica, carbon dioxide, fluorine, and, in most samples, sulphate are the predominating constituents of domestic phosphate rock. Magnesium, titanium, sodium, potassium, manganese, chromium, copper, zinc, arsenic, chlorine, and iodine are present in nearly all samples, but only in comparatively small quantities. Small percentages of vanadium are also present in many samples.

Phosphate rock from continental deposits usually contains 3 to 4 percent of fluorine, whereas that from insular deposits contains smaller quantities. As a general rule, the fluorine-phosphoric acid ratios in a particular type of rock are approximately constant. Although fresh bones are very low in fluorine, fossil bones frequently contain high percentages of this element. Evidence is presented to show that the fluorine in phosphate rock and fossil bones originates principally from contact of the phosphates with fluorine-bearing waters, and that, to a certain extent, there is a rough correlation between the fluorine content and the geological age of these materials.

The commercial types and grades of domestic phosphate rock contain approximately the following percentages of minor constituents—

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MgO, 0.0 to 0.5; TiO_2, 0.03 to 0.15; Na_2O, 0.1 to 0.8; K_2O, 0.05 to 0.65; MnO, traces to 0.3; Cr_2O_3, 0.00 to 0.15; V_2O_3, 0.00 to 0.40; CuO, <0.0005 to 0.01; ZnO, <0.0005 to 0.025; As_2O_3, 0.001 to 0.015; and Cl, 0.00 to 0.10. The iodine content ranges from approximately 1 to 130 parts per million.

Pyrite is a common constituent of Tennessee blue rock and phosphatic limestone, South Carolina land rock, and rock from Cokeville, Wyo.

The organic matter isolated from phosphate rock carries high percentages of nitrogen and sulphur, and the ash of this material is rich in iron.

In comparison with the other types of domestic phosphate rock, Tennessee brown-rock phosphate is characterized by the presence of high percentages of aluminum, iron, and manganese, and by the absence of vanadium. It usually contains more potassium than sodium, whereas the reverse is the rule with the other types.

Tennessee blue-rock phosphate is similar to Tennessee brown rock in that it is comparatively high in iron. It is also high in acid-soluble sulphate, but its outstanding characteristic is its high content of acid-insoluble sulphide, principally pyrite.

Florida land-pebble phosphate has no outstanding chemical characteristic. The percentages of fluorine in the different commercial grades of this material are, however, approximately constant, whereas in the other types of phosphate rock the fluorine content varies, as a general rule, directly with the phosphoric acid.

Florida hard-rock phosphate is characterized by its comparatively high content of iodine and low content of sulphate and chlorine.

In general, the phosphates from deposits in the Rocky Mountain States are comparatively high in chromium and vanadium, and low in iodine. Certain samples, notably those from deposits at Conda, Idaho, and Cokeville, Wyo., are exceptionally high in organic carbon and organic sulphur, whereas rock from the Garrison, Mont., deposit is low in organic carbon and in total sulphur.

In comparison with phosphate rock, Florida waste-pond phosphate is low in phosphoric acid and exceptionally high in silica and alumina. The composition of Florida soft phosphate varies considerably with different samples.

Nearly all of the elements present in phosphate rock occur also in bone ash.

Analyses of the mechanical fractions separated from samples of ground phosphate rock and from Florida soft and waste-pond phosphates showed that, as a general rule, the phosphoric acid, calcium, and fluorine concentrate somewhat in the "sand" and "silt" fractions, whereas the alumina and silica concentrate to a marked extent in the "clay" and colloid fractions, particularly the latter.

Phosphate rock does not contain significant quantities of phosphoric acid soluble in neutral ammonium citrate solution, and less than 30 percent of the total phosphoric acid is soluble in 2 percent citric acid solution. The percentages of phosphoric acid dissolved by these reagents from a particular sample of phosphate increase with increase in the fineness of the particles.

The principal phosphatic component of phosphate rock from continental deposits is fluorapatite, which is present almost entirely in the submicrocrystalline condition. Hydroxy fluorapatite is an im-

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portant constituent of rock from insular deposits. The available data indicate that domestic phosphate rock may contain small quantities of carbonate apatite and hydroxyapatite.

LITERATURE CITED

(1) ANONYMOUS.
1931. NEW CHEMICAL INDUSTRY FOR THE SOUTH. Manufacturers Rec. 99 (15):38–40, illus.

(2) AITA, A.
1916. RICERCHE SULLA SOLUBILITÀ DEI FOSFATI MINERALI. Ann. Chim. Appl. [Rome] 6:28–44, illus.

(3) ———
1916. CAUSE CHE INFLUISCONO SULLA SOLUBILITÀ IN ACIDO CITRICO DEI FOSFATI DIFFICILMENTE SOLUBILI. Ann. Chim. Appl. [Rome] 6:119–131, illus.

(4) ALEXANDER, L. T., and JACOB, K. D.
1930. MECHANICAL ANALYSIS OF FINELY DIVIDED NATURAL PHOSPHATES. U. S. Dept. Agr. Tech. Bul. 212, 24 p., illus.

(5) ARTINI, E.
1912. OSSERVAZIONI PETROGRAFICHE SU DI ALCUNE ROCCE FOSFATICHE DELLA PALESTINA. Atti Soc. Ital. Sci. Nat. Milano 50:349–364, illus.

(6) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1930. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. COMPILED BY THE COMMITTEE ON EDITING METHODS OF ANALYSIS. Ed. 3, 593 p., illus. Washington, D. C.

(7) BETHKE, R. M., KICK, C. H., EDGINGTON, B. H., and WILDER, O. H.
1930. THE EFFECT OF FEEDING SODIUM FLUORIDE AND ROCK PHOSPHATE ON BONE DEVELOPMENT IN SWINE. A PRELIMINARY REPORT. Amer. Soc. Anim. Prod. Proc. 1929:29–33.

(8) BLACKWELDER, E.
1910. PHOSPHATE DEPOSITS EAST OF OGDEN, UTAH. U.S. Geol. Survey Bul. 430:536–551, illus.

(9) ———
1911. A RECONNAISSANCE OF THE PHOSPHATE DEPOSITS IN WESTERN WYOMING. U.S. Geol. Survey Bul. 470:452–481, illus.

(10) BORGSTRÖM, L. H.
1931. SYNTETISK NaCl-APATIT. Finska Kemistsamfundets Meddel. 40: [51]–54, illus.

(11) BRANNER, J. C.
1896. THE PHOSPHATE DEPOSITS OF ARKANSAS. Amer. Inst. Mining Engin. Trans. 26:580–598, illus.

(12) ——— and NEWSOM, J. F.
1902. THE PHOSPHATE ROCKS OF ARKANSAS. Ark. Agr. Expt. Sta. Bul. 74, p. [61]–123, illus.

(13) BRAUN.
1896. UNTERSUCHUNGEN ÜBER DEN FLUORGEHALT VON PHOSPHATEN, SUPERPHOSPHATEN, KNOCHENMEHLEN UND GUANOS. Chem. Indus. [Berlin] 19:181–185.

(14) BREDIG, M. A., FRANCK, H. H., and FÜLDNER, H.
1932. BEITRÄGE ZUR KENNTNIS DER KALK-PHOSPHORSÄURE-VERBINDUNGEN. Ztschr. Elektrochem. 38:158–164, illus.

(15) CARLES, P.
1907. LE FLUOR DANS LES EAUX MINÉRALES. Compt. Rend. Acad. Sci. [Paris] 144:37–39.

(16) ———
1907. LE FLUOR DANS LES COQUILLES DE MOLLUSQUES. Compt. Rend. Acad. Sci. [Paris] 144:437–438.

(17) ———
1907. LE FLUOR DANS LES COQUILLES DES MOLLUSQUES NON MARINS. Compt. Rend. Acad. Sci. [Paris] 144:1240.

(18) CARNOT, A.
1892. RECHERCHE DU FLUOR DANS DIFFÉRENTES VARIÉTÉS DE PHOSPHATES NATURELS. Compt. Rend. Acad. Sci. [Paris] 114: 1003–1006.

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(19) Carnot, A.
1892. RECHERCHE DU FLUOR DANS LES OS MODERNES ET LES OS FOSSILES. Compt. Rend. Acad. Sci. [Paris] 114:1189–1192.

(20) ———
1892. SUR LA COMPOSITION DES OSSEMENTS FOSSILES ET LA VARIATION DE LEUR TENEUR EN FLUOR DANS LES DIFFÉRENTS ÉTAGES GÉOLOGIQUES. Compt. Rend. Acad. Sci. [Paris] 115:243–246.

(21) ———
1892. SUR UNE APPLICATION DE L'ANALYSE CHIMIQUE POUR FIXER L'ÂGE D'OSSEMENTS HUMAINS PRÉHISTORIQUES. Compt. Rend. Acad. Sci. [Paris] 115:337–339.

(22) ———
1893. RECHERCHES SUR LA COMPOSITION GÉNÉRALE ET LA TENEUR EN FLUOR DES OS MODERNES ET DES OS FOSSILES DES DIFFÉRENTS AGES. Ann. Mines (9) 3:155–195.

(23) ———
1894. SUR LA COMPOSITION CHIMIQUE DES WAVELLITES ET DES TURQUOISES. Compt. Rend. Acad. Sci. [Paris] 118:995–998.

(24) ———
1896. SUR LES VARIATIONS OBSERVÉES DANS LA COMPOSITION DES APATITES. Compt. Rend. Acad. Sci. [Paris] 122:1375–1380.

(25) ———
1896. SUR LE MODE DE FORMATION DES GÎTES SÉDIMENTAIRES DE PHOSPHATE DE CHAUX. Compt. Rend. Acad. Sci. [Paris] 123:724–729.

(26) ———
1896. SUR LES VARIATIONS OBSERVÉES DANS LA COMPOSITION DES APATITES, DES PHOSPHORITES ET DES PHOSPHATES SÉDIMENTAIRES. REMARQUES SUR LE GISEMENT ET LE MODE DE FORMATION DE CES PHOSPHATES. Ann. Mines (9) 10:137–231.

(27) Carpenter, F. B.
1894. THE MARLS AND PHOSPHATES OF NORTH CAROLINA. N.C. Agr. Expt. Sta. Bul. 110, p. [455]–504, illus.

(28) Casares, J., and Casares, R.
1930. SOBRE LA INVESTIGACION CUALITATIVA DEL FLUOR EN LOS HUESOS. An. Soc. Españ. Fís. Quím. 28:910–915.

(29) Chazal, P. E.
1904. THE CENTURY IN PHOSPHATES AND FERTILIZERS. A SKETCH OF THE SOUTH CAROLINA PHOSPHATE INDUSTRY. 71 p., illus. Charleston.

(30) Churchill, H.V.
1931. OCCURRENCE OF FLUORIDES IN SOME WATERS OF THE UNITED STATES. Indus. and Engin. Chem. 23:996–998, illus.

(31) Clarke, F. W., Schneider, E. A., Hillebrand, W. F., Melville, W. H., Eakins, L. G., and Stokes, H. N.
1893. REPORT OF WORK DONE IN THE DIVISION OF CHEMISTRY DURING THE FISCAL YEARS 1891–'92 AND 1892–'93. U. S. Geol. Survey Bul. 113, 115 p., illus.

(32) ———
1924. THE DATA OF GEOCHEMISTRY. U.S. Geol. Survey Bul. 770, Ed. 5, 841 p.

(33) ——— and Wheeler, W. C.
1922. THE INORGANIC CONSTITUENTS OF MARINE INVERTEBRATES. U.S. Geol. Survey Prof. Paper 124, Ed. 2, rev. and enl., 62 p.

(34) Condit, D. D.
1924. PHOSPHATE DEPOSITS IN THE WIND RIVER MOUNTAINS NEAR LANDER, WYOMING. U.S. Geol. Survey Bul. 764, 39 p., illus.

(35) ——— Finch, E. H., and Pardee, J. T.
1928. PHOSPHATE ROCK IN THE THREE FORKS–YELLOWSTONE PARK REGION, MONTANA. U.S. Geol. Survey Bul. 795:147–209, illus.

(36) Cristiani, H.
1930. LA PÉRIODE LARVÉE DE L'INTOXICATION FLUORIQUE. Compt. Rend. Soc. Biol. [Paris] 103:292–294.

(37) Dabney, C. W., Jr.
1884. NORTH CAROLINA RESOURCES FOR COMMERCIAL FERTILIZERS. I. PHOSPHATES. N.C. Agr. Expt. Sta. Ann. Rpt. 1883:57–83.

(38) ———
1885. THE PHOSPHATE EXPLORATION. N.C. Agr. Expt. Sta. Ann. Rpt. 1884:44–84, illus.

Digitized by Microsoft®

(39) DANA, E. S.
1914. THE SYSTEM OF MINERALOGY OF JAMES DWIGHT DANA, 1837–1868. Ed. 6, entirely rewritten and much enl., 1134 p., illus. New York and London.

(40) DAY, D. T.
1885. FERTILIZERS. PHOSPHATE ROCK. U.S. Geol. Survey Min. Resources U. S. 1883–84:783–794.

(41) ———
1886. FERTILIZERS. PHOSPHATE ROCK. U.S. Geol. Survey Min. Resources U. S. 1885:445–458.

(42) DITTE, A.
1886. RECHERCHES SUR LES APATITES ET LES WAGNÉRITES. Ann. Chim. Phys. (6) 8:502–542.

(43) DUSSERT, D.
1924. LES GISEMENTS ALGÉRIENS DE PHOSPHATE DE CHAUX. Ann. Mines (12) 6:135–221, 229–325, 333–398, 407–451, illus.

(44) ELDRIDGE, G. H.
1893. A PRELIMINARY SKETCH OF THE PHOSPHATES OF FLORIDA. Amer. Inst. Mining Engin. Trans. 21:196–231, illus.

(45) FELLENBERG, T. VON
1926. DAS VORKOMMEN, DER KREISLAUF UND DER STOFFWECHSEL DES JODS. Ergeb. Physiol. 25:176–363, illus.

(46) ———
1927. UNTERSUCHUNGEN ÜBER DAS VORKOMMEN VON JOD IN DER NATUR. XI. MITTEILUNG: ZUR GEOCHEMIE DES JODS. II. Biochem. Ztschr. 187:1–6.

(47) ——— and LUNDE, G.
1926. UNTERSUCHUNGEN ÜBER DAS VORKOMMEN VON JOD IN DER NATUR. X. MITTEILUNG. BEITRAG ZUR GEOCHEMIE DES JODS. Biochem. Ztschr. 175:[162]–171.

(48) FIELDNER, A. C., SELVIG, W. A., and TAYLOR, G. B.
1919. THE DETERMINATION OF COMBUSTIBLE MATTER IN SILICATE AND CARBONATE ROCKS. U. S. Dept. Int., Bur. Mines Tech. Paper 212, 22 p., illus.

(49) FOERSTE, A. [F].
1913. THE PHOSPHATE DEPOSITS IN THE UPPER TRENTON LIMESTONES OF CENTRAL KENTUCKY. Ky. Geol. Survey (4) 1 (pt. 1):391–439, illus.

(50) GALE, H. S.
1911. ROCK PHOSPHATE NEAR MELROSE, MONTANA. U.S. Geol. Survey Bul. 470:440–451, illus.

(51) ——— and RICHARDS, R. W.
1910. PRELIMINARY REPORT ON THE PHOSPHATE DEPOSITS IN SOUTHEASTERN IDAHO AND ADJACENT PARTS OF WYOMING AND UTAH. U.S. Geol. Survey Bul. 430:457–535, illus.

(52) GARNER, W. W., MCMURTREY, J. E., JR., BOWLING, J. D., JR., and MOSS, E. G.
1930. MAGNESIUM AND CALCIUM REQUIREMENTS OF THE TOBACCO CROP. Jour. Agr. Research 40:145–168, illus.

(53) GAUTIER, A., and CLAUSMANN, P.
1914. LE FLUOR DANS LES EAUX DOUCES. Compt. Rend. Acad. Sci. [Paris] 158:[1389]–1395.

(54) ——— and CLAUSMANN, P.
1914. LE FLUOR DANS LES EAUX MINÉRALES. Compt. Rend. Acad. Sci. [Paris] 158:1631–1640.

(55) GILE, P. L., MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U.S. Dept. Agr. Bul. 1193, 42 p.

(56) GRAMMONT, A.
1924. ÉTUDE SUR LES PHOSPHATES NATURELS.—RECHERCHE ET DOSAGE DES MÉTAUX CONTENUS EN PETITE QUANTITÉ DANS CES MINÉRAUX. Bul. Soc. Chim. France (4) 35:405–408.

(57) ———
1924. ÉTUDE SUR LES PHOSPHATES NATURELS.—RECHERCHE ET DOSAGE DES MÉTAUX CONTENUS EN PETITE QUANTITÉ DANS CES MINÉRAUX (2e NOTE). Bul. Soc. Chim. France (4) 35:1351–1354.

166350°—33——6

Digitized by Microsoft®

(58) GRAY, A. N.
1930. PHOSPHATES AND SUPERPHOSPHATES. 275 p. London.
(59) HAUSEN, H.
1926. TILL FRÅGAN OM APATITERNAS KEMISKA FORMEL. Finska Kemistsamfundets Meddel. 35:[9]–18, illus.
(60) HAYES, C. W.
1895. THE TENNESSEE PHOSPHATES. U.S. Geol. Survey Ann. Rpt. 16 (pt. 4):610–630, illus.
(61) ———
1896. THE TENNESSEE PHOSPHATES. U.S. Geol. Survey Ann. Rpt. 17 (pt. 2):519–550, illus.
(62) ———
1903. ORIGIN AND EXTENT OF THE TENNESSEE WHITE PHOSPHATES. U.S. Geol. Survey Bul. 213:418–423.
(62a) HAYES, C. W., and ULRICH, E. O.
1903. DESCRIPTION OF THE COLUMBIA QUADRANGLE. U.S. Geol. Survey Geol. Atlas of U.S. Columbia Folio Tennessee no. 95, 6 p., illus.
(63) HEADDEN, W. P.
1910. THE OCCURRENCE OF ARSENIC IN SOILS, PLANTS, FRUITS, AND ANIMALS. Colo. Sci. Soc. Proc. 9:[345]–360.
(64) HENDRICKS, S. B., HILL, W. L., JACOB, K. D., and JEFFERSON, M. E.
1931. STRUCTURAL CHARACTERISTICS OF APATITE-LIKE SUBSTANCES AND COMPOSITION OF PHOSPHATE ROCK AND BONE AS DETERMINED FROM MICROSCOPICAL AND X-RAY DIFFRACTION EXAMINATIONS. Indus. and Engin. Chem. 23:1413–1418, illus.
(65) ——— JEFFERSON, M. E., and MOSLEY, V. M.
1932. THE CRYSTAL STRUCTURES OF SOME NATURAL AND SYNTHETIC APATITE-LIKE SUBSTANCES. Ztschr. Kristallographie 81:352–369, illus.
(66) HERCUS, C. E., BENSON, W. N., and CARTER, C. L.
1925. ENDEMIC GOITRE IN NEW ZEALAND, AND ITS RELATION TO THE SOIL-IODINE. Jour. Hyg. [London] 24:321–402, illus.
(67) ——— and ROBERTS, K. C.
1927. THE IODINE CONTENT OF FOODS, MANURES AND ANIMAL PRODUCTS IN RELATION TO THE PROPHYLAXIS OF ENDEMIC GOITRE IN NEW ZEALAND. Jour. Hyg. [London] 26:49–83, illus.
(68) HESS, F. L.
1925. COBALT, MOLYBDENUM, NICKEL, TANTALUM, TITANIUM, TUNGSTEN, RADIUM, URANIUM, AND VANADIUM IN 1922. U.S. Geol. Survey Min. Resources U.S. 1922 (pt. 1):557–583.
(69) HILL, W. L., and JACOB, K. D.
1930. DETERMINATION OF SILICA IN PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 13:112–117.
(70) ——— and JACOB, K. D.
1933. DETERMINATION AND OCCURRENCE OF IODINE IN PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 16: 128–137.
(71) ——— JACOB, K. D., ALEXANDER, L. T., and MARSHALL, H. L.
1930. CHEMICAL AND PHYSICAL COMPOSITION OF CERTAIN FINELY DIVIDED NATURAL PHOSPHATES FROM FLORIDA. Indus. and Engin. Chem. 22:1392–1396, illus.
(72) ——— MARSHALL, H. L., and JACOB, K. D.
1932. COMPOSITION OF CRUDE PHOSPHORIC ACID PREPARED BY SULFURIC ACID PROCESS. Indus. and Engin. Chem. 24:1064–1068, illus.
(73) ——— MARSHALL, H. L., and JACOB, K. D.
1932. MINOR METALLIC CONSTITUENTS OF PHOSPHATE ROCK. Indus. and Engin. Chem. 24:1306–1312, illus.
(74) ——— MARSHALL, H. L., and JACOB, K. D.
1933. OCCURRENCE OF SULPHUR, ORGANIC MATTER, NITROGEN, AND WATER IN PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 16: 260–276.
(75) HILLEBRAND, W. F.
1900. DISTRIBUTION AND QUANTITATIVE DETERMINATION OF VANADIUM AND MOLYBDENUM IN ROCKS OF THE UNITED STATES. U.S. Geol. Survey Bul. 167:49–55.
(76) ———
1919. THE ANALYSIS OF SILICATE AND CARBONATE ROCKS. U.S. Geol. Survey Bul. 700, 285 p., illus.

Digitized by Microsoft®

(77) HILLEBRAND, W. F. and LUNDELL, G. E. F.
1929. APPLIED INORGANIC ANALYSIS; WITH SPECIAL REFERENCE TO THE ANALYSIS OF METALS, MINERALS, AND ROCKS. 929 p., illus. New York and London.

(78) HINTZE, C.
1924. HANDBUCH DER MINERALOGIE. Bd. 1, Lieferung 22, p. 487–572, illus.

(79) HOFFMAN, J. I., and LUNDELL, G. E. F.
1929. DETERMINATION OF FLUORINE AND OF SILICA IN GLASSES AND ENAMELS CONTAINING FLUORINE. U.S. Dept. Com., Bur. Standards Jour. Research 3:581–595.

(80) HOLMES, F. S.
1870. PHOSPHATE ROCKS OF SOUTH CAROLINA AND THE "GREAT CAROLINA MARL BED," . . . TOGETHER WITH THEIR HISTORY AND DEVELOPMENT. 87 p., illus. Charleston.

(81) HOOK, J. S.
1914. THE BROWN AND BLUE PHOSPHATE ROCK DEPOSITS OF SOUTH-CENTRAL TENNESSEE. Resources Tenn.: [451]–83, illus.

(82) ———
1915. THE WHITE PHOSPHATES OF TENNESSEE. Resources Tenn. 5:[23]–33, illus.

(83) IHLSENG, M. C.
1896. A PHOSPHATE PROSPECT IN PENNSYLVANIA. U.S. Geol. Survey Ann. Rpt. (1895–96) 17 (pt. 3, continued):955–957.

(84) JACOB, K. D., BEESON, K. C., RADER, L. F., JR., and ROSS, W. H.
1931. THE SOLUBILITY OF PHOSPHATES IN NEUTRAL AMMONIUM CITRATE SOLUTION. Jour. Assoc. Off. Agr. Chem. 14:263–283.

(85) ——— HILL, W. L., and HOLMES, R. S.
1930. THE COLLOIDAL NATURE OF SOME FINELY DIVIDED NATURAL PHOSPHATES. Colloid Symposium Annual, v. 7, p. 195–204. New York and London.

(86) ——— RADER, L. F., JR., MARSHALL, H. L., and BEESON, K. C.
1932. CITRATE-INSOLUBLE PHOSPHORIC ACID IN DI- AND TRICALCIUM PHOSPHATES; SOME FACTORS AFFECTING ITS DETERMINATION. Indus. and Engin. Chem., Analyt. Ed. 4:25–31, illus.

(87) ——— RADER, L. F., JR., and ROSS, W. H.
1932. COMPARISON OF TWO PER CENT CITRIC ACID AND NEUTRAL AMMONIUM CITRATE SOLUTIONS, AS SOLVENTS FOR PHOSPHATES. Jour. Assoc. Off. Agr. Chem. 15:146–162.

(88) ——— and REYNOLDS, D. S.
1928. THE FLUORINE CONTENT OF PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 11:237–250.

(89) ——— and ROSS, W. H.
1932. DETERMINATION OF AVAILABLE PHOSPHORIC ACID BY THE NEUTRAL AMMONIUM CITRATE METHOD. Commercial Fertilizer Yearbook, p. 19–26, 46.

(90) JENKINS, O. P.
1916. PHOSPHATES AND DOLOMITES IN JOHNSON COUNTY, TENNESSEE. Resources Tenn. 6:[51]–106, illus.

(91) JOHNSON, B. L.
1930. PHOSPHATE ROCK. PART I—GENERAL INFORMATION. U.S. Dept. Com., Bur. Mines Inform. Circ. 6256, 64 p., illus.

(92) JONES, C. C.
1914. THE DISCOVERY AND OPENING OF A NEW PHOSPHATE FIELD IN THE UNITED STATES. Amer. Inst. Mining Engin. Trans. 47:192–216, illus.

(93) JUMEAU, L. P.
1905. LE PHOSPHATE DE CHAUX (GISEMENTS CONNUS) ET LES EXPLOITATIONS AUX ÉTATS-UNIS EN 1905. 198 p., illus. Paris.

(94) KNOP, J.
1924. DIPHENYLAMINE AS INDICATOR IN THE TITRATION OF IRON WITH DICHROMATE SOLUTION. Jour. Amer. Chem. Soc. 46:[263]–269.

(95) LACROIX, A.
1910. SUR LA CONSTITUTION MINÉRALOGIQUE DES PHOSPHORITES FRANÇAISES. Compt. Rend. Acad. Sci. [Paris] 150:1213–1217.

Digitized by Microsoft®

(96) LACROIX, A.
1910. SUR LE MINÉRAL À STRUCTURE OPTIQUE ENROULÉE CONSTITUANT LES PHOSPHORITES HOLOCRISTALLINES DU QUERCY. Compt. Rend. Acad. Sci. [Paris] 150:1388–1390.

(97) LAMAR, J. E.
1926. PRELIMINARY REPORT ON THE ECONOMIC MINERAL RESOURCES OF CALHOUN COUNTY. Ill. Geol. Survey Rpt. Invest. 8, 21 p., illus.

(98) LAPP, M. E.
1932. CHANGES IN THE OFFICIAL AND TENTATIVE METHODS OF ANALYSIS MADE AT THE FORTY-SEVENTH ANNUAL CONVENTION, NOVEMBER 2–4, 1931. Jour. Assoc. Off. Agr. Chem. 15:65–87.

(99) LARISON, E. L.
1929. MANUFACTURE OF HIGH-ANALYSIS PHOSPHATES. Indus. and Engin. Chem. 21:1172–1175, illus.

(100) LARSEN, E. S., and SHANNON, E. V.
1930. THE MINERALS OF THE PHOSPHATE NODULES FROM NEAR FAIRFIELD, UTAH. Amer. Mineralogist 15:307–337, illus.

(101) LASNE, H.
1890. IDENTITÉ DE COMPOSITION DE QUELQUES PHOSPHATES SÉDIMENTAIRES AVEC L'APATITE. Compt. Rend. Acad. Sci. [Paris] 110:1376–1377.

(102) LAWRENCE, H. M., and ROCCA, E.
1931. FLOTATION OF LOW-GRADE PHOSPHATE ORES. II. U.S. Dept. Com., Bur. Mines Rpt. Invest. 3105, 9 p.

(103) LIPMAN, J. G.
1929. THE FERTILIZING VALUE OF MANY MINERALS . . . Amer. Fert. 70 (1): [19]–25, 55–56, 58, 60, 62.

(104) LUNDELL, G. E. F., and HOFFMAN, J. I.
1924. THE ANALYSIS OF PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 8:184–206.

(105) MCCALLEY, H.
1900. ALABAMA PHOSPHATES ON AND NEAR ELK RIVER, LIMESTONE COUNTY. Ala. Dept. Agr. Bul. 14:15–16.

(106) MCCALLIE, S. W.
1896. A PRELIMINARY REPORT ON A PART OF THE PHOSPHATES AND MARLS OF GEORGIA. Ga. Geol. Survey Bul. 5–A, 98 p., illus.

(107) MCCLURE, F. J., and MITCHELL, H. H.
1931. THE EFFECT OF CALCIUM FLUORIDE AND PHOSPHATE ROCK ON THE CALCIUM RETENTION OF YOUNG GROWING PIGS. Jour. Agr. Research 42:363–373, illus.

(108) MCHARGUE, J. S.
1925. THE OCCURRENCE OF COPPER, MANGANESE, ZINC, NICKEL, AND COBALT IN SOILS, PLANTS, AND ANIMALS, AND THEIR POSSIBLE FUNCTION AS VITAL FACTORS. Jour. Agr. Research 30:193–196.

(109) ———
1931. REPORT ON LESS COMMON METALS IN SOILS. Jour. Assoc. Off. Agr. Chem. 14:138–141.

(110) ——— ROY, W. R., and PELPHREY, J. G.
1930. IODINE IN SOME FERTILIZER MATERIALS. Amer. Fert. 73 (10):40, 42, 63.

(111) ——— YOUNG, D. W., and ROY, W. R.
1932. DETERMINATION OF IODINE IN SOILS. A NEW METHOD. Indus. and Engin. Chem., Analyt. Ed. 4:214–216, illus.

(112) MANSFIELD, G. R.
1916. A RECONNAISSANCE FOR PHOSPHATE IN THE SALT RIVER RANGE, WYOMING. U.S. Geol. Survey Bul. 620:331–349, illus.

(113) ———
1917. THE PHOSPHATE RESOURCES OF THE UNITED STATES. 2nd Pan Amer. Sci. Cong. Proc., sec. 7, v. 8, p. 729–766, illus.

(114) ———
1920. GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF THE FORT HALL INDIAN RESERVATION, IDAHO. U.S. Geol. Survey Bul. 713:9–119, illus.

(115) ———
1925. PHOSPHATE ROCK. U.S. Geol. Survey Min. Resources U.S. 1922 (pt. 2):109–132.

Digitized by Microsoft®

(116) MANSFIELD, G. R.
1926. PHOSPHATE ROCK. U.S. Geol. Survey Min. Resources U.S. 1923 (pt. 2):239–273.

(117) ———
1927. PHOSPHATE ROCK. U.S. Dept. Com., Bur. Mines, Min. Resources U.S. 1924 (pt. 2):77–112.

(118) ———
1929. GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF THE PORTNEUF QUADRANGLE, IDAHO. U.S. Geol. Survey Bul. 803, 110 p., illus.

(119) ——— and GIRTY, G. H.
192 . GEOGRAPHY, GEOLOGY, AND MINERAL RESOURCES OF PART OF SOUTHEASTERN IDAHO . . . WITH DESC IPTIONS OF THE CARBONIFEROUS AND TRIASSIC FOSSILS. U.S. Geol. Survey Prof. Paper 152, 453 p., illus.

(120) MARSHALL, H. L., JACOB, K. D., and REYNOLDS, D. S.
1932. OCCURRENCE OF FLUORINE IN NATURAL PHOSPHATES; FUETHER STUDIES. Indus. and Engin. Chem. 24:86–89.

(121) MARTINI, A.
1929. UEBER DAS VORKOMMEN VON NICKEL IN DEN KNOCHEN. Mikrochemie 7:235.

(122) MATSON, G. C.
1915. THE PHOSPHATE DEPOSITS OF FLORIDA. U.S. Geol. Survey Bul. 604, 101 p., illus.

(123) MAYNARD, T. P.
1913. WHITE ROCK PHOSPHATES OF DECATUR COUNTY, TENN. Resources Tenn., 3:161–169, illus.

(124) MEMMINGER, C. G.
1895. COMMERCIAL DEVELOPMENT OF THE TENNESSEE PHOSPHATE. U.S. Geol. Survey Ann. Rpt. 16 (pt. 4):631–635.

(125) ——— WAGGAMAN, W. H., and WHITNEY, W. T.
1930. THE CALCINATION OR ENRICHMENT OF PHOSPHATE ROCK. Indus. and Engin. Chem. 22:443–446, illus.

(126) MILLAR, C. C. H.
1892. FLORIDA, SOUTH CAROLINA, AND CANADIAN PHOSPHATES: GIVING A COMPLETE ACCOUNT OF THEIR OCCURRENCE, METHODS, AND COST OF PRODUCTION, QUANTITIES RAISED, AND COMMERCIAL IMPORTANCE. 223 p., illus. London.

(127) MOSES, O. A.
1883. THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA. U.S. Geol. Survey Min. Resources U.S. 1882:504–521.

(128) MURRAY, J., and RENARD, A. F.
1891. REPORT ON DEEP-SEA DEPOSITS, BASED ON THE SPECIMENS COLLECTED DURING THE VOYAGE OF H.M.S. CHALLENGER IN THE YEARS 1872 TO 1876. 525 p., illus. London, Edinburgh, [etc.].

(129) NELSON, W. A.
1913. MINERAL PRODUCTS ALONG THE TENNESSEE CENTRAL RAILROAD. Resources Tenn. 3:[137]–160, illus.

(130) ÖPIK, A.
1928. GISEMENTS DE PHOSPHATES EN ESTHONIE; DER ESTLAENDISCHE OBOLENPHOSPHORIT. Les réserves mondiales en phosphates: Bur. 14th Cong. Géol. Internat. Espagne, 1926, v. 1, p. 135–192, illus. Madrid.

(131) ORR, J. B., and LEITCH, I.
1929. IODINE IN NUTRITION: A REVIEW OF EXISTING INFORMATION. [Gt. Brit.] Med. Research Council, Spec. Rpt. Ser. 123, 108 p., illus.

(132) PAPISH, J., HOAG., L. E., and SNEE, W. E.
1930. SPECTROSCOPIC DETECTION OF FLUORINE. Indus. and Engin. Chem., Analyt. Ed. 2:263–264, illus.

(133) PARDEE J. T.
1913. SOME FURTHER DISCOVERIES OF ROCK PHOSPHATE IN MONTANA. U.S. Geol. Survey Bul. 530:285–291, illus.

(134) ———
1917. THE GARRISON AND PHILIPSBURG PHOSPHATE FIELDS, MONTANA. U.S. Geol. Survey Bul. 640:195–228, illus.

Digitized by Microsoft ®

(135) PARDEE, J. T.
1921. PHOSPHATE ROCK NEAR MAXVILLE, GRANITE COUNTY, MONTANA. U.S. Geol. Survey Bul. 715:141–145, illus.

(136) PARRISH, P., and OGILVIE, A.
1927. ARTIFICIAL FERTILISERS, THEIR CHEMISTRY, MANUFACTURE, & APPLICATION. v. 1, 356 p., illus. London.

(137) PENROSE, R. A. F., JR.
1888. NATURE AND ORIGIN OF DEPOSITS OF PHOSPHATE OF LIME. U.S. Geol. Survey Bul. 46:21–143, illus.

(138) PHALEN, W. C.
1912. BAUXITE AND ALUMINUM. U.S. Geol. Survey Min. Resources U.S. 1911 (pt. 1):923–939, illus.

(139) ———
1915. REPORT ON THE PHOSPHATE ROCKS OF CENTRAL KENTUCKY. 80 p., illus. Frankfort, Ky.

(140) ———
1917. THE CONSERVATION OF PHOSPHATE ROCK IN THE UNITED STATES. 2nd Pan Amer. Sci. Cong. Proc., sec. 7, v. 8, p. 772–808, illus.

(141) PHILLIPS, W. B.
1887. THE FERTILIZER TRADE IN NORTH CAROLINA IN 1886. U.S. Geol. Survey Min. Resources U.S. 1886:611–617.

(142) ———
1901. THE BAT GUANO CAVES OF TEXAS. Mines and Minerals 21:440–442, illus.

(143) PIKE, R. D.
1930. VOLATILIZATION OF PHOSPHORUS FROM PHOSPHATE ROCK. I. EXPERIMENTS IN CRUCIBLES AND ROTARY KILN. Indus. and Engin. Chem. 22:242–245, illus.

(144) ———
1930. VOLATILIZATION OF PHOSPHORUS FROM PHOSPHATE ROCK. II. EXPERIMENTS IN THE VOLATILIZATION OF PHOSPHORUS AND POTASH IN A BLAST FURNACE. Indus. and Engin. Chem. 22:344–349, illus.

(145) PRATT, N. A.
1868. ASHLEY RIVER PHOSPHATES. HISTORY OF THE MARLS OF SOUTH CAROLINA AND OF THE DISCOVERY AND DEVELOPMENT OF THE NATIVE BONE PHOSPHATES OF THE CHARLESTON BASIN . . . 42 p., illus. Philadelphia.

(146) PURDUE, A. H.
1907. DEVELOPED PHOSPHATE DEPOSITS OF NORTHERN ARKANSAS. U.S. Geol. Survey Bul. 315:463–473.

(147) REED, O. E., and HUFFMAN, C. F.
1930. THE RESULTS OF A FIVE YEAR MINERAL FEEDING INVESTIGATION WITH DAIRY CATTLE. Mich. Agr. Expt. Sta. Tech. Bul. 105, 63 p., illus.

(148) REEDS, C. A.
1910. A REPORT ON THE GEOLOGICAL AND MINERAL RESOURCES OF THE ARBUCKLE MOUNTAINS, OKLAHOMA. Okla. Geol. Survey Bul. 3, 69 p., illus.

(149) REITH, J. F.
1930. DER JODGEHALT VON MEERWASSER. Rec. Trav. Chim. 49:142–150.

(150) REYNOLDS, D. S., and JACOB, K. D.
1931. METHOD FOR DETERMINATION OF FLUORINE IN PHOSPHATE ROCK AND PHOSPHATIC SLAGS. Indus. and Engin. Chem., Analyt. Ed. 3:366–370.

(151) ——— and JACOB, K. D.
1931. EFFECT OF CERTAIN FORMS OF SILICA ON DETERMINATION OF FLUORINE BY VOLATILIZATION METHOD. Indus. and Engin. Chem., Analyt. Ed. 3:371–373.

(152) ——— JACOB, K. D., and HILL, W. L.
1929. RATIO OF FLUORINE TO PHOSPHORIC ACID IN PHOSPHATE ROCK. Indus. and Engin. Chem. 21:1253–1256.

(153) ——— ROSS, W. H., and JACOB, K. D.
1928. VOLATILIZATION METHOD FOR THE DETERMINATION OF FLUORINE WITH SPECIAL REFERENCE TO THE ANALYSIS OF PHOSPHATE ROCK. Jour. Assoc. Off. Agr. Chem. 11:225–236, illus.

Digitized by Microsoft ®

(154) RICHARDS, R. W., and MANSFIELD, G. R.
1911. PRELIMINARY REPORT ON A PORTION OF THE IDAHO PHOSPHATE RESERVE. U.S. Geol. Survey Bul. 470:371–439, illus.

(155) ——— and MANSFIELD, G. R.
1914. GEOLOGY OF THE PHOSPHATE DEPOSITS OF GEORGETOWN, IDAHO. U.S. Geol. Survey Bul. 577, 76 p., illus.

(156) ——— and PARDEE, J. T.
1926. THE MELROSE PHOSPHATE FIELD, MONTANA. U.S. Geol. Survey Bul. 780:1–32, illus.

(157) ROBERTSON, G. S.
1914. THE SOLUBILITY OF MINERAL PHOSPHATES IN CITRIC ACID. Jour. Soc. Chem. Indus. 33:9–11.

(158) ———
1916. NOTES ON THE NATURE OF THE PHOSPHATES CONTAINED IN MINERAL PHOSPHATES. Jour. Agr. Sci. [England] 8:[16]–25, illus.

(159) ——— and DICKINSON, F.
1923. THE VALUATION OF INSOLUBLE PHOSPHATES BY MEANS OF A MODIFIED CITRIC ACID TEST. Jour. Soc. Chem. Indus. 42:59T–66T, illus.

(160) ROBINSON, W. O.
1914. THE INORGANIC COMPOSITION OF SOME IMPORTANT AMERICAN SOILS. U.S. Dept. Agr. Bul. 122, 27 p.

(161) ———
1922. THE ABSORPTION OF WATER BY SOIL COLLOIDS. Jour. Phys. Chem. 26:[647]–653.

(162) ——— and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U.S. Dept. Agr. Bul. 1311, 42 p.

(163) ROGERS, G. S.
1915. THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA. U.S. Geol. Survey Bul. 580:183–220, illus.

(164) ROSEBERRY, H. H., HASTINGS, A. B., and MORSE, J. K.
1931. X-RAY ANALYSIS OF BONE AND TEETH. Jour. Biol. Chem. 90:395–408, illus.

165) ROSS. B. B.
1900. PHOSPHATES OF THE ELK RIVER VALLEY IN LIMESTONE COUNTY, ALABAMA. Ala. Dept. Agr. Bul. 14:[5]–15.

(166) ROSS, W. H., and JACOB, K. D.
1931. REPORT ON PHOSPHORIC ACID: AVAILABILITY OF THE REVERTED PHOSPHORIC ACID IN AMMONIATED SUPERPHOSPHATES. Jour. Assoc. Off. Agr. Chem. 14:182–196.

(167) ——— JACOB, K. D., and BEESON, K. C.
1932. REPORT ON PHOSPHORIC ACID: COMPOSITION AND FERTILIZER EFFICIENCY OF THE INSOLUBLE PHOSPHATES IN AMMONIATED SUPERPHOSPHATES. Jour. Assoc. Off. Agr. Chem. 15:227–266.

(168) ——— and MERZ, A. R.
1931. PHOSPHORIC ACID. *In* Wiley, H. W., Principles and Practice of Agricultural Analysis; A Manual for the Study of Soils, Fertilizers, and Agricultural Products, for the Use of Analysts, Teachers, and Students of Agricultural Chemistry. v. 2. Fertilizers and Insecticides. Ed. 3, rev. and enl., p. [41]–212, illus. Easton, Pa.

(169) SCHALLER, W. T.
1912. MINERALOGICAL NOTES, SERIES 2. U.S. Geol. Survey Bul. 509, 115 p., illus.

(170) SCHOCH, E. P.
1918. CHEMICAL ANALYSES OF TEXAS ROCKS AND MINERALS. Tex. Univ. Bul. 1814, 256 p.

(171) SCHREINER, O.
1929. THE RÔLE OF THE RARER ELEMENTS IN SOILS, FOODS, AND DRUGS. Jour. Assoc. Off. Agr. Chem. 12:16–30, illus.

(172) SCHUCHT, L.
1926. DIE FABRIKATION DES SUPERPHOSPHATES MIT BERÜCKSICHTIGUNG DER ANDEREN GEBRÄUCHLICHEN DÜNGEMITTEL. Ed. 4, 372 p., illus. Braunschweig.

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(173) SCHULTZ, A. R.
1918. A GEOLOGIC RECONNAISSANCE FOR PHOSPHATE AND COAL IN SOUTHEASTERN IDAHO AND WESTERN WYOMING. U.S. Geol. Survey Bul. 680, 84 p., illus.

(174) ———
1919. A GEOLOGIC RECONNAISSANCE OF THE UINTA MOUNTAINS, NORTHERN UTAH, WITH SPECIAL REFERENCE TO PHOSPHATE. U.S. Geol. Survey Bul. 690:31–94, illus.

(175) ——— and RICHARDS, R. W.
1913. A GEOLOGIC RECONNAISSANCE IN SOUTHEASTERN IDAHO. U.S. Geol. Survey Bul. 530:267–284, illus.

(176) SELLARDS, E. H.
1910. A PRELIMINARY PAPER ON THE FLORIDA PHOSPHATE DEPOSITS. Fla. Geol. Survey Ann. Rpt. 3:[21]–41, illus.

(177) ———
1915. THE PEBBLE PHOSPHATES OF FLORIDA. Fla. Geol. Survey Ann. Rpt. 7:[25]–116, illus.

(178) SHALER, N. S.
1888. REPORT ON THE GEOLOGY OF MARTHA'S VINEYARD. U.S. Geol. Survey Ann. Rpt. (1885–86) 7:303–363, illus.

(179) SHEAD, A. C.
1923. PHOSPHATE ROCKS IN OKLAHOMA. Okla. Acad. Sci. Proc. 3:97–102, illus. (Okla. Univ. Bul. (n.s.) 271).

(180) ———
1923. PHOSPHATE IN PERMIAN RED BEDS OF OKLAHOMA AND TEXAS. Chem. Age [New York] 31:319–320.

(181) SHEPARD, C. U., JR.
1880. SOUTH CAROLINA PHOSPHATES. 29 p., illus. Charleston, S.C.

(182) ———
1880. SOUTH CAROLINA PHOSPHATES AND THEIR PRINCIPAL COMPETITORS IN THE MARKETS OF THE WORLD. S.C. Commr. Agr. Ann. Rpt. 1:68–115, illus.

(183) SMITH, E. A.
1892. ON THE PHOSPHATES AND MARLS OF ALABAMA. Ala. Geol. Survey Bul. 2, 82 p.

(184) ———
1895. PHOSPHATES AND MARLS OF ALABAMA. Amer. Inst. Mining Engin. Trans. 25:811–822.

(185) ——— and MCCALLEY, H.
1904. INDEX TO MINERAL RESOURCES OF ALABAMA. Ala. Geol. Survey [Bul. 9], 79 p., illus.

(185a) SMITH, H. V., and SMITH, M. C.
1932. MOTTLED ENAMEL IN ARIZONA AND ITS CORRELATION WITH THE CONCENTRATION OF FLUORIDES IN WATER SUPPLIES. Ariz. Agr. Expt. Sta. Tech. Bul. 43, p. [213]–287, illus.

(186) SMITH, R. W.
1926. GEOLOGY AND UTILIZATION OF TENNESSEE PHOSPHATE ROCK. Amer. Inst. Mining and Metall. Engin. Trans. 74:127–146, illus.

(187) STARYNKEVICH-BORNEMAN, I. D.
1924. SUR LA PRESENCE DES TERRES RARES DANS LES APATITES. Compt. Rend. Acad. Sci. Russie (A):39–41.

(188) STONE, R. W.
1920. PHOSPHATE ROCK. U.S. Geol. Survey Min. Resources U.S. 1917 (pt. 2):7–18.

(189) ——— and BONINE, C. A.
1915. THE ELLISTON PHOSPHATE FIELD, MONTANA. U.S. Geol. Survey Bul. 580:373–383, illus.

(190) STOSE, G. W.
1907. PHOSPHORUS ORE AT MOUNT HOLLY SPRINGS, PA. U.S. Geol. Survey Bul. 315:474–483.

(191) ———
1914. PHOSPHATE DEPOSITS IN SOUTHWESTERN VIRGINIA. U.S. Geol. Survey Bul. 540:383–396, illus.

(192) STUBBS, W. C.
1885. PHOSPHATE ROCK, ALABAMA. U.S. Geol. Survey Min. Resources U.S. 1883–84:794–803.

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(193) TANAKADATE, H. S., and CAROBBI, G.
1929. SOPRA UN NUOVO GIACIMENTO DI APATITE IN CINA. Rend. Accad. Sci. Fis. e Mat. Napoli (4) 35:116–132, illus.

(193a) THOMPSON, T. G., and TAYLOR, H. J.
1933. DETERMINATION AND OCCURRENCE OF FLUORIDES IN SEA WATER. Indus. and Engin. Chem., Analyt. Ed. 5:87–89.

(194) WAGGAMAN, W. H.
1910. A REVIEW OF THE PHOSPHATE FIELDS OF IDAHO, UTAH, AND WYOMING, WITH SPECIAL REFERENCE TO THE THICKNESS AND QUALITY OF THE DEPOSITS. U.S. Dept. Agr., Bur. Soils Bul. 69, 48 p., illus.

(195) ———
1911. A REVIEW OF THE PHOSPHATE FIELDS OF FLORIDA. U.S. Dept. Agr., Bur. Soils Bul. 76, 23 p.

(196) ———
1912. A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS. U.S. Dept. Agr., Bur. Soils Bul. 81, 36 p., illus.

(197) ———
1913. A REPORT ON THE PHOSPHATE FIELDS OF SOUTH CAROLINA. U.S. Dept. Agr. Bul. 18, 12 p., illus.

(198) ———
1914. THE RESERVE SUPPLY OF PHOSPHATE ROCK IN THE UNITED STATES. Jour. Indus. and Engin. Chem. 6:464–465.

(199) ——— and EASTERWOOD, H. W.
1927. PHOSPHORIC ACID, PHOSPHATES, AND PHOSPHATIC FERTILIZERS. 370 p., illus. New York.

(200) ——— EASTERWOOD, H. W., and TURLEY, T. B.
1923. INVESTIGATIONS OF THE MANUFACTURE OF PHOSPHORIC ACID BY THE VOLATILIZATION PROCESS. U.S. Dept. Agr. Bul. 1179, 55 p., illus.

(201) WAGNER, C. R., and ROSS, W. H.
1917. A MODIFIED METHOD FOR THE DETERMINATION OF FLUORINE WITH SPECIAL APPLICATION TO THE ANALYSIS OF PHOSPHATES. Jour. Indus. and Engin. Chem. 9:1116–1123, illus.

(202) WATSON, T. L.
1907. MINERAL RESOURCES OF VIRGINIA. 618 p., illus. Lynchburg, Va.

(203) ——— and GOOCH, S. D.
1918. VIVIANITE FROM THE LAND PEBBLE PHOSPHATE DEPOSITS OF FLORIDA. Jour. Wash. Acad. Sci. 8:82–88.

(204) ——— and TABER, S.
1913. GEOLOGY OF THE TITANIUM AND APATITE DEPOSITS OF VIRGINIA. Va. Geol. Survey Bul. 3-A, 308 p., illus.

(205) WELLER, S.
1907. NOTES ON THE GEOLOGY OF SOUTHERN CALHOUN COUNTY. Ill. Geol. Survey Bul. 4:[219]–233.

(206) WILBER, F. A.
1883. APATITE. U.S. Geol. Survey Min. Resources U. S. 1882:521.

(207) WILKE-DÖRFURT, E., BECK, J., and PLEPP, G.
1928. ÜBER DAS VORKOMMEN VON JOD IN PHOSPHATLAGERN. Ztschr. Anorg. Allgem. Chem. 172:344–352, illus.

(208) WRIGHT, C. D.
1893. THE PHOSPHATE INDUSTRY OF THE UNITED STATES. U.S. Commr. Labor Spec. Rpt. 6, 145 p., illus.

(209) WYATT, F.
1892. THE PHOSPHATES OF AMERICA; WHERE AND HOW THEY OCCUR; HOW THEY ARE MINED; AND WHAT THEY COST. . . . Ed. 4, 187 p., illus. New York.

(210) ZIES, E. G.
1929. THE VALLEY OF TEN THOUSAND SMOKES. I. THE FUMAROLIC INCRUSTATIONS AND THEIR BEARING ON ORE DEPOSITION. II. THE ACID GASES CONTRIBUTED TO THE SEA DURING VOLCANIC ACTIVITY. Natl. Geogr. Soc. Contributed Tech. Papers (Katmai Ser.) 1, no. 4, 79 p., illus.

(211) ZUCCÀRI, G.
1913. SULLA PRESENZA DELL'ARSENICO COME ELEMENTO NORMALE NELLE TERRE. Gaz. Chim. Ital. 43 (pt. 2):398–403.

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BIOLOGY OF BRACHYMERIA FONSCOLOMBEI (DUFOUR), A HYMENOPTEROUS PARASITE OF BLOWFLY LARVAE

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INTRODUCTION

Brachymeria fonscolombei (Dufour), a hymenopterous parasite of Diptera, has been known as a parasite of blowflies for nearly a hundred years. Recently it has come under consideration because of the frequency with which it is reared from blowfly larvae. It is the purpose of this bulletin to discuss the biology and behavior of this parasite, with detailed reference to its preferred hosts. These experiments were begun at Uvalde, Tex., in 1928, and were concluded in 1932. Uvalde County, in the Lower Sonoran of the Lower Austral faunal zone, has an average altitude of 937 feet, an average annual rainfall of 23.71 inches, and an annual mean temperature of 69.7° F.

In southwestern Texas the blowflies, especially the screw-worm fly (*Cochliomyia macellaria* Fab.), are of major importance because of their abundance and their depredations on livestock. In the past the loss of cattle, goats, and sheep caused by blowflies, and particularly the attacks of flies on young calves, kids, and lambs, have at times practically prohibited the breeding of livestock. In recent years conditions have improved. The adoption of progressive and modern

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range methods by ranchmen has lowered the losses considerably. Among these practices may be listed the eradication of cattle ticks, the bite of which was an invitation to fly attack, improved methods of moving and handling cattle, fly trapping, and the prevention of maggot breeding by the burning or burial of animal carcasses. Although bodies of goats, cattle, and other large animals may be destroyed in this manner, numerous smaller carcasses necessarily escape the attention of the ranchman. Many of these small ones are devoured by buzzards and other scavengers, but some of them and portions of others remain as breeding places for flies.

Climatological factors, chemical and bacteriological conditions within the carrion, predators, and competition between the various species of insect larvae combine, during the natural destruction of a carcass, to limit the number and specific nature of blowfly larvae which will mature. Regardless, however, of the united effect of all these natural factors, many maggots complete their development. The importance of a blowfly parasite is measured by the extent of its infestation of host larvae which would otherwise reach maturity in a particular piece of carrion.

A number of parasites attack these maggots, and in addition numerous predators destroy matured fly larvae. Studies are being made of these insects to determine their economic value, both as individual species and collectively as a group, under different climatic and ecological conditions. It is hoped that among these parasites and predators certain species may be found which, if encouraged by artificial means, will form a complex of parasites and predators that will act effectively in blowfly control.

SYSTEMATIC POSITION

Brachymeria fonscolombei is a species of the subfamily Chalcidinae, family Chalcididae, superfamily Chalcidoidea, and order Hymenoptera. Although it was known previously under other names, Dufour (*3*) [1] described the species in 1841, naming it after Boyer de Fonscolombe, and calling attention to the fact that it should be placed in the genus Brachymeria erected by Westwood (*14*) in 1832. However, it continued to be known under the generic name Chalcis until 1923, when the generic name Brachymeria was definitely recognized by Gahan and Fagan (*4*).

DISTRIBUTION

Brachymeria fonscolombei is generally distributed over central Europe, extending into Russia and Asia. Specimens collected in Batavia, Java, are in the United States National Museum. In North America it has been found throughout the southern part of the United States, from Florida to California and as far north as Illinois. Specimens are known from Mexico and Haiti.

The records of distribution in Europe have been taken from literature. The distribution in the United States and Mexico is based on specimens collected or examined by the author.

Europe.—Italy: Tuscany (*11*), Liguria (*7*), Sicily (*13*); France: Var (*9*), southern France (*3*); Spain: Province of Madrid (*8*), Province of Ciudad Real (*8*); Austria:

[1] Italic numbers in parentheses refer to Literature Cited, p. 21.

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Lower Austria (*12*), Tyrol (*12*), Küstenland (*12*); Herzegovina· Stolac (*12*); Germany: Brandenburg (*12*); Sweden: southern part (*2*); Russia: Transcaucasia (*12*), Waluiki (*12*).

Asia.—Nord-Mongolei (*12*); Java: Batavia.

North America.—Mexico: Tampico, Tamaulipas; West Indies: Port au Prince, Haiti; United States: Arizona, Arkansas, California, Florida, Illinois, Kansas, Louisiana, Oklahoma, Maryland, Mississippi, New Mexico, Texas.

DESCRIPTION

The original description of *Brachymeria fonscolombei* by Dufour (*3, p. 16*) was published in 1841. Additional descriptions have been made by Mercet (*8*), Ruschka (*12*), Masi (*6, 7*), and others. Parker (*10*), in 1924, gave descriptions and figures of the egg and larval stages. These various descriptions state that the length of adults of *B. fonscolombei* ranges from 3.5 to 6 mm. Dufour (*3, p. 17*) says that it varies greatly in size like *Chalcis minuta*, and this difference in size is independent of sex. The adult female is shown in Figure 1.

FIGURE 1.—Adult female of *Brachymeria fonscolombei*. × 12. (Drawing by C. Lewis.)

SIZE OF ADULTS

Specimens in the collection at Uvalde, Tex., indicate variations of from 3 to 6 mm in length. Sex of the individuals is partly the cause of this variation, but the differences are mainly due to the species of the host and the size of the host larva at time of pupation. The larger species of flies, such as *Sarcophaga plinthopyga* Wied., when the larvae receive plenty of food and are fully developed, produce *B. fonscolombei* 6 mm long. On the other hand, *Lucilia sericata*. Meig. and

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Cochliomyia macellaria Fab. produce the same species of parasites 4 mm long, and if the host larvae are undernourished, the parasites are only 3 mm in length. The following measurements are averages of specimens bred from pure strains of flies.

Host:	*Length of parasite adult (millimeters)*
Sarcophaga plinthopyga Wied	4 to 6
Phormia regina Meig	3 to 6
Lucilia unicolor Towns	4
Calliphora coloradensis Hough	4
Synthesiomyia nudiseta V.d.W	3.5 to 4
Lucilia sericata Meig	3 to 4
Cochliomyia macellaria Fab	3.5

Conclusive proof that variations in size occur between the sexes was demonstrated by measuring the lengths of the individuals of the progenies of four female *B. fonscolombei*. In each instance the host was *S. plinthopyga*. In a total of 146 progeny from the four female *B. fonscolombei*, 71 males ranged in length from 4 to 5 mm, averaging 4.7 mm, whereas 75 females ranged between 5.5 and 6 mm, averaging 5.9 mm.

PROPORTION OF THE SEXES

Tests, in which jars, each containing 4 ounces of meat, were exposed and the flies and parasites reared therefrom, were conducted to determine the proportion of sexes in *B. fonscolombei*. Necessarily, the entire emergence of parasites from each test was considered, as the males emerge slightly sooner than the females. Great variation in the proportion of males and females was indicated by the results of the individual tests, but the averages were more consistent. In one test 70 percent were males and 30 percent were females, while in another 22 percent were males and 78 percent were females. The averages for 1930 and 1931 were 45.15 percent males and 54.85 percent females. These latter figures are comparable with those secured from the tests of 1932, which gave 42.41 percent males and 57.59 percent females. An average of all these, based on the emergence of 3,543 *B. fonscolombei*, shows that 43.04 percent were males and 56.96 percent were females. These results indicate a moderate preponderance of females over males.

REPRODUCTION

MATING

Under favorable conditions of warm, bright weather the mating preliminaries of *B. fonscolombei*, in cages, commence almost immediately after the emergence of the parasites. These preliminaries for adults that have emerged during the night or early morning hours are usually well under way by 9 a.m.

The males are attracted to the females and continually follow them about. When two or more couples are together, they change partners frequently, two males often contesting for a female. After about half an hour of preliminary measures the insects mate, the act lasting about 30 seconds. No female has been observed to permit a male to mate with her more than once, although a male will attempt a second mating. Apparently only a single fertilization is required by a female.

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OVIPOSITION

Numerous tests have been conducted to determine the length of the preoviposition period. Unmated males and females of known ages, each of which had emerged in a separate glass vial, were used. In each test oviposition was secured within 24 hours after the emergence of the parasite. The shortest preoviposition period was 3 hours, but as males only were secured from eggs deposited during this period, it might be concluded that they were produced by a female that had not been fertilized. However, female offspring resulted from eggs deposited by this insect when it was between 6 and 8 hours old. In one test female offspring were secured from eggs laid before the end of a 7½-hour preoviposition period and in another test before the end of a 6-hour period. It is shown, therefore, that male offspring can be produced from eggs deposited 3 hours after emergence of the parent parasite, and both male and female offspring from eggs laid less than 6 hours after the emergence of the parents. The shortest recorded period between mating of adults and deposition of eggs that produced females was 5 hours. However, from observations it appears that the period between mating and oviposition may be somewhat less than this.

The parasites manifest no preference for any particular portion of the larva for egg laying. There is no indication that they choose the posterior spiracles or stigmal plate, although they have been seen to oviposit there.

Frequently the juices from meat in which larvae have fed will induce *B. fonscolombei* to oviposit. When an individual larva has been offered to a parasite and oviposition is delayed, if the larva is dipped in the juice surrounding the meat and returned to the parasite, oviposition often occurs immediately. Moreover, on numerous occasions oviposition has been brought about by placing a drop of meat juice on the inside of a glass vial and introducing a female *B. fonscolombei*. A parasite has been seen to deposit therein as many as five eggs, in much the same manner as when parasitizing a larva.

As a rule, preliminary to oviposition, the parasite makes a thorough examination of the larva by use of the antennae. During this investigation the female constantly touches the larva with its antennae, then, as though dissatisfied, moves away, perhaps to return again immediately. Females sometimes compete for a larva, the larger or stronger repulsing the other by use of the hind legs.

The adult of *B. fonscolombei* may attack the larva in one of two ways. It may approach the host and, after touching it several times with the antennae, turn, and, bracing the body with the legs, thrust in the ovipositor. The parasite, during this process, appears clumsy, as if unsure of the distance and direction of the host. Often several thrusts will be made with the ovipositor before the host is encountered. The second mode of attack is more efficient. The parasite grasps the larva with the hind legs. While in this position, it has no difficulty in inserting and driving in the ovipositor, and the larva has little chance to escape.

The time required for oviposition is 5 to 15 seconds. Deposition of the egg by the parasite has been observed under a binocular while the fly larva was held between two glass slides. Transmitted light

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made it possible to see into and through the maggot. A portion of the body exposed at the edge of the slides permitted attack by the parasite. Oviposition was observed as a simple process in which the ovipositor was thrust through the body wall into the body cavity. The issuing of the egg from the ovipositor took place in an interesting way. First appeared a portion of the chorion, which so quickly filled with the egg contents that it momentarily took the form of a globe; the remainder of the chorion followed immediately and the egg assumed its cylindrical shape. This process required less than a second. The egg floated at once in the body cavity, propelled back and forth by muscular actions of the larva's body. Only one egg was seen to be deposited at a single thrust of the ovipositor.

Immediately upon being attacked, the larva begins thrashing around in an attempt to dislodge its attacker. The parasite, if firmly braced, may be able to hold its position until the ovipositor is withdrawn. If the parasite is on the side of a jar or piece of meat, in a position above the larva, it may even lift the larva into the air, swinging it around for a second. More frequently, however, and especially when the parasite mounts the larva, the pair are thrown into a struggle, each trying to break away.

Following oviposition, the parasite may withdraw and perhaps spend a moment in cleaning the antennae and head, or it may resume oviposition immediately. The larva, on the other hand, continues to thrash about as if suffering from the attack. Sometimes the larva is attacked two or more times in succession.

Eggs have been observed from oviposition until hatching. At 20 hours segmentation is evident, by 24 hours the embryo is twisting about within the egg, and on the third day hatching occurs.

NUMBER OF PARASITES DEVELOPING FROM A SINGLE HOST LARVA

A common habit of *B. fonscolombei* is to deposit more than one egg in a single host larva. A single parasite has been seen to attack a larva as many as 12 times. Frequently when fly larvae are dissected, from 3 to 5 parasite eggs are found in a single larva. In the course of these studies thousands of parasitized blowfly pupae have been isolated in individual glass vials and the parasites allowed to emerge. In no instance has more than one *B. fonscolombei* issued from a single fly pupa. Numerous tests have been conducted in which parasitized fly larvae have been placed under a binocular, illuminated, and the number of parasite eggs counted. Specimens with 2 or 3 parasite eggs were isolated and upon pupation were placed in individual glass vials. Only one parasite emerged from each pupa. In dissecting fly larvae, twin parasite larvae are often found to have developed to the second stage. Apparently after the second stage only one parasite continues to develop.

NUMBER OF EGGS PRODUCED BY A SINGLE FEMALE

The number of eggs which a female *B. fonscolombei* can lay has not been definitely ascertained. From a single female 80 offspring, 26 males and 54 females, were obtained. This represents the largest number of individuals produced by a single parasite under observation. On April 29, 1930, two females were dissected. The first, a medium-sized gravid female, 3 days old, contained 87 perfectly formed eggs

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and many more so small that they could not be counted. The second was smaller and contained 85 large eggs. On June 24, 1930, two large, 3-day-old gravid females were examined. In one, 164 clearly formed eggs were found, and 177 in the other. There were numerous smaller immature eggs.

PARTHENOGENESIS

An unfertilized *B. fonscolombei* female will produce fertile eggs, but male offspring only will result. A series of 10 unmated females produced a total of 204 male and no female progeny, and the average developmental period for this series was 19.5 days. In each of these tests the parent parasite emerged from a pupa that had been kept in an individual glass vial, so that any possibility of contact with a male was eliminated. A test was made to determine the fertility of the males produced by virgin females. A male was selected from the progeny of an unmated female and mated with a virgin female that had emerged in an individual glass vial. This pair produced 10 male and 20 female offspring. The appearance of females in this generation is ample proof of the fertility of males produced by virgin females.

DEVELOPMENTAL PERIOD OF IMMATURE STAGES

METHODS

The method used in determining the period between the parasitization of the fly larvae and the emergence of *B. fonscolombei* consisted in exposing fly larvae to parasites under outside conditions and rearing under careful observation the parasites produced therefrom.

FIGURE 2.—Jars used as containers of meat baits in breeding immature stages of *Brachymeria fonscolombei* Jar on left shows large-mesh cover used during exposure; jar on right has cover of brass strainer cloth used to close jars after exposure.

In all the tests pint Mason jars were used. Each jar contained 1½ inches of slightly moist sand on which was placed a 4-ounce piece of fresh rabbit meat. Each jar was marked with a gummed label showing all data concerning the exposure. Figure 2 shows the breeding jars, and Figure 3 shows the method of exposing the jars in the field.

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Ordinarily 6 jars were used in each test, though in some instances the number ranged from 2 to 10. The jars were all exposed under similar conditions, protected only from the sun. In some cases the meat was infested with larvae within the laboratory before exposure and therefore the day of exposure was known to be the exact date parasitization occurred. When meat was exposed without being infested and remained exposed several days, all conditions were carefully checked, and then the day of probable greatest parasitization was chosen as the date from which to figure the beginning of the developmental period. In selecting this date, temperature and weather conditions were studied and observations made to record the appearance of the parent parasites in the jars and their period of greatest activity.

FIGURE 3.—Jar containing meat bait exposed for infestation by blowflies and their parasites. The wooden shelter is protection against rain and animals.

There was no attempt to regulate the species of host flies in these tests. However, species of Sarcophaga predominated. The flies were allowed to infest the meat in a natural way. The relative proportion of species emerging in the jars was roughly as follows:

Species:	*Percent*
Sarcophaga spp	75
Lucilia spp	10
Phormia regina Meig	5
Synthesiomyia nudiseta V.d.W	3
Cochliomyia macellaria Fab	2
Others	5

At the conclusion of the tests the jars were capped with tops of 60-mesh brass strainer cloth and placed on shelves in an insectary where they were under daily observation. Conditions in this insectary approached, as nearly as possible, natural conditions. Shade was the

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only protection given the jars, the screened walls permitting outdoor temperatures to prevail. Each insect was determined and recorded the day of its emergence.

LENGTH OF DEVELOPMENTAL PERIOD

Emergence records for each test are listed in table 1. These tests were carried out during 1928, 1929, and 1930, and include records of parasites bred from exposures during the months from March to November, inclusive. Each record presents the number of parasites that emerged, the range in the developmental period, and the average developmental period for the group.

TABLE 1.—*Summary of tests showing developmental period of Brachymeria fonscolombei in blowfly larvae, Uvalde, Tex., 1928, 1929, and 1930*

Date fly larvae were parasitized	Summer broods						Overwintering broods					
	Range of developmental period	Average length of developmental period	Total parasites in summer brood	Temperatures			Range of developmental period	Average length of developmental period	Total parasites in overwintering brood	Temperatures		
				Maximum	Minimum	Average of daily means				Maximum	Minimum	Average of daily means
	Days	*Days*	*Number*	°*F.*	°*F.*	°*F.*	*Days*	*Days*	*Number*	°*F.*	°*F.*	°*F.*
Mar. 25, 1929	26–33	27	456	97	53	75	-------	-------	-------	-------	-------	-------
Mar. 27, 1930	32–37	35	12	95	30	70	-------	-------	-------	-------	-------	-------
Apr. 10, 1930	27–36	32	12	94	47	75	-------	-------	-------	-------	-------	-------
May 6, 1930	25–27	26	5	94	47	76	-------	-------	-------	-------	-------	-------
May 21, 1930	23–36	26	137	97	60	78	-------	-------	-------	-------	-------	-------
June 5, 1930	20–27	22	181	100	64	81	-------	-------	-------	-------	-------	-------
June 27, 1928	17–26	21	870	104	73	88	-------	-------	-------	-------	-------	-------
July 11, 1928	20–29	24	265	102	70	86	-------	-------	-------	-------	-------	-------
Aug. 1, 1930	18–24	21	22	104	70	86	-------	-------	-------	-------	-------	-------
Aug. 2, 1930	19–26	21	81	104	65	86	-------	-------	-------	-------	-------	-------
Aug. 3, 1930	16–22	19	43	104	70	86	-------	-------	-------	-------	-------	-------
Sept. 4, 1930	20–26	23	30	102	59	82	-------	-------	-------	-------	-------	-------
Oct. 5, 1928	42–69	51	9	94	28	63	171–191	178	37	100	20	60
Oct. 15, 1928	42–83	49	44	89	20	57	163–181	173	376	100	20	59
Oct. 20, 1928	78–93	82	8	87	20	56	156–176	167	318	100	20	59
Oct. 22, 1928	-------	-------	-------	-------	-------	-------	143–174	166	302	100	20	59
Oct. 27, 1928	-------	-------	-------	-------	-------	-------	156–169	164	182	100	20	58
Oct. 30, 1928	-------	-------	-------	-------	-------	-------	153–165	161	62	100	20	58
Nov. 3, 1928	-------	-------	-------	-------	-------	-------	149–155	150	20	100	20	57
Nov. 6, 1928	-------	-------	-------	-------	-------	-------	153–156	155	11	100	20	58
Total	16–93	-------	2,175	-------	-------	-------	143–191	-------	1,308	-------	-------	-------

Many host larvae and pupae from these tests were dissected in the laboratory, and it was found that in warm weather the period from the hatching of the parasite larva until it reached maturity was from 8 to 12 days. The host larva pupates during this period, and the parasite larva continues its feeding until the host pupa is destroyed, after which it in turn pupates and remains in this stage for a period of about 10 to 12 days.

Temperatures (Fahrenheit) during these tests were recorded from the date the larvae were parasitized until the end of the emergence period of the parasites. For each test the extreme maximum and minimum and the average of the daily means are given.

In the course of these tests 3,483 *B. fonscolombei* were reared. A satisfactory test was started as early as March 25. The average developmental period in this case was 27 days. Thereafter, generally

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speaking, with the increase of daily mean temperatures this period shortened. During August an average period of 19 days, a minimum mean for the tests, was recorded. After August the period of development rapidly lengthened. Of the brood starting from October 1 to 20, only part emerged, and the remainder overwintered within the host. Of those starting late in October and in November, all overwintered in immature forms.

The shortest period of development for immature stages encountered was from a test initiated August 3, 1930. From larvae parasitized on this date, two *B. fonscolombei* emerged on August 19, after a period of 16 days. The average developmental period for this entire group was 19 days, while the average for all tests conducted during August was 20 days.

The longest period noted for the development of an individual that did not overwinter in immature form was 93 days. This was a parasite which emerged January 21, 1929, from an egg deposited October 20, 1928. The greatest period for an overwintering individual was 191 days, from October 5, 1928, to April 14, 1929.

RELATION OF TEMPERATURE TO DEVELOPMENT

The effect of variations in temperature on the development of *B. fonscolombei* is plainly evident. On the basis of the data summarized in table 1, the developmental periods may be arranged in groups, each with an average daily mean temperature range of 5°. The average lengths of the developmental periods of the groups are as follows:

Range (° F.):	*Period (days)*
86 to 90	21.5.
81 to 85	22.
76 to 80	26.
71 to 75	27.
66 to 70	35.
61 to 65	51 (some overwinter).
56 to 60	55 (some overwinter).
Below 55	No fall emergence; all overwinter.

The minimum temperature for ordinary activity and development was near 65° F. In the fall, in periods where the mean temperature fell below 65°, a portion of the brood overwintered. Oviposition was secured in 1929 throughout October and early November. At this time daily maxima of 65° or higher were suitable for oviposition by *B. fonscolombei*, but the mean temperature for the period, being below 65°, precluded complete development of the parasites.

From the last emergence of a parasite of a summer brood of 1928 until the first emergence of one from an overwintering brood in 1929, the average daily mean temperature was 54° F., with a maximum of 93° and a minimum of 20°.

In 1930 oviposition was secured as late as November 18. On this date four adult *B. fonscolombei* were active at 3 p.m. The temperature at that time was 80° F., the maximum for the day, the minimum for the previous night being 43°.

NUMBER OF GENERATIONS PER YEAR

In calculating the number of generations of *B. fonscolombei* per year, it is necessary to determine the length of the immature stages during each month throughout the year and derive the number of generations

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therefrom. Naturally, the breeding habits of this insect bring about an overlapping of generations which precludes a periodic rise and fall in the population curve. Although the members of the overwintering generation emerge almost simultaneously, several factors unite to induce variations in the following broods. Delays may arise through the difficulties of individuals in locating hosts. These discrepancies may be accentuated in successive generations by variations in the length of the developmental periods of individuals.

Before computing the length of a generation, it was necessary to assume an arbitrary preoviposition period. In fixing this period, certain factors had to be considered. While it has been shown that females, given perfect conditions, can oviposit within a few hours after emergence, it must be remembered that unsuitable conditions will bring about delays. Also, in the field, the males and females may not find each other readily, and subsequent to mating, the females must locate the host larvae. The longer preoviposition periods of spring and fall will tend to increase the average period for the year. From these considerations a preoviposition period of three days was selected.

At Uvalde *B. fonscolombei* ordinarily appears and begins to oviposit about March 20. From late in March to mid November climatic conditions at Uvalde are favorable to the development of *B. fonscolombei*. If host larvae are available throughout this period, eight generations might occur, a portion of the eighth overwintering in immature stages. As previously explained, these generations overlap. Figure 4 indicates the number of generations that might occur per year on the basis of the average developmental period for each month. It should be clearly understood that the number of generations shown in this figure represents the maximum number of generations possible during the season, on the basis of the average developmental periods during the various months, and does not necessarily represent the seasonal cycle in the field.

LONGEVITY

It is evident from numerous observations that neither food nor water is necessary for adults of *B. fonscolombei* previous to oviposition. However, they will partake readily of water and will feed upon bananas or other fruit. It is likely that the adults secure water and perhaps food from the juices present on the meats which they frequent and upon the liquids which often surround fly larvae. Certain foods lengthen the life of *B. fonscolombei*, but water alone seems to have no effect.

Increased temperature decreases the length of life. Adults held in captivity without food or water at temperatures with a mean of from 80° to 90° F. lived from 1 to 6 days, the average being 2.5 days. At a mean temperature of 70° to 79° the longevity was from 1 to 6 days and the average 3.6 days. Below 60° (50° to 59°) the range was from 7 to 23 days and the average 9.4 days. When the insects were given water only at a mean temperature of from 80° to 90° the length of life was from 1 to 5 days and the average 2.8. Banana and water both being given, at a mean of from 80° to 89°, the longevity was from 1 to 6 days and the average 3.8 days; at a mean temperature of from 70° to 79° the range was from 2 to 6 days and the average 4.5 days; at a mean temperature of 60° to 69° it was from 3 to 6 days and the

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average 5.6 days. Provided with a diet of honey only, at a mean temperature of from 80° to 90°, the insects lived from 1 to 23 days, the average life being 11 days.

These longevity tests were made, so far as temperature and humidity were concerned, under natural conditions. It was necessary, however, to confine the Brachymeria in cages that permitted daily observations. Two types of cages were used; one consisted of pint Mason jars with screen tops, the other of 10-inch screen cylinders, 6 inches in diameter. The results obtained with the two types of cages were about the same.

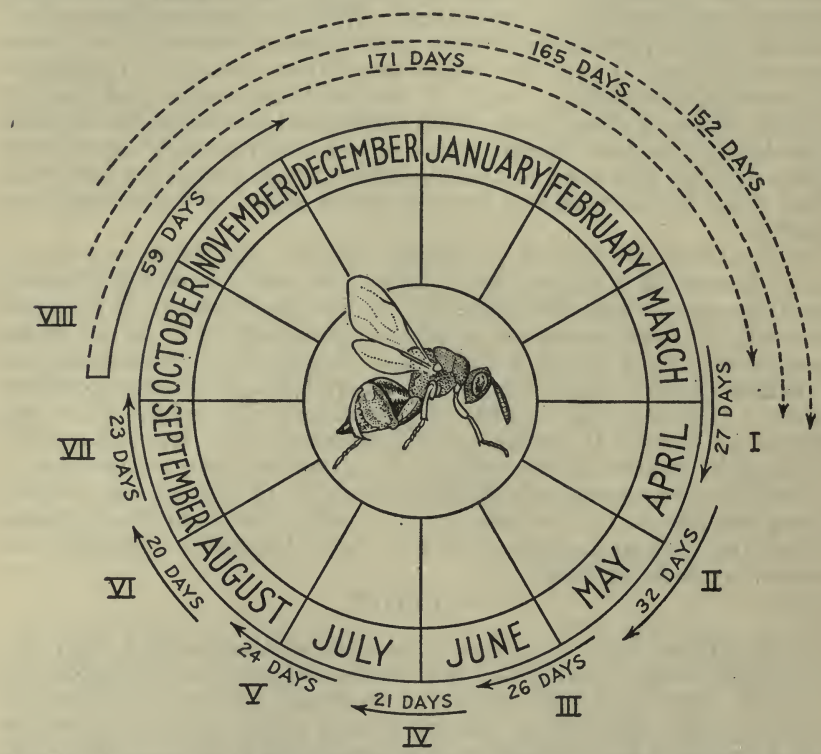

FIGURE 4.—A calendar year for *Brachymeria fonscolombei* at Uvalde, Tex., showing maximum number of generations per year and average length of developmental period of parasite. Summer broods are represented by solid lines, overwintering broods by broken lines.

Water was given in a small glass dish containing a sponge. Banana, when used, was sliced, a fresh slice being furnished each day. The honey was not diluted; and it had no opportunity to ferment, as fresh honey, on a sponge, was supplied daily.

An extensive study was not made of the difference in longevity of the sexes. Incomplete data and observations indicate that the male outlives the female by a day.

HIBERNATION

Brachymeria fonscolombei passes the winter in the last larval or prepupal stage within the host pupa. The relation of temperature to overwintering is discussed under Developmental Period of Immature

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Stages, where it is shown that in October and November, when the average mean daily temperature goes below 65° F., a portion of the last summer brood of parasites overwinters in the immature form. *B. fonscolombei* has been carried successfully through the winter in pure strains of *Sarcophaga plinthopyga, Cochliomyia macellaria,* and numerous mixtures of Sarcophaga and Lucilia. Examination of the blowfly pupae from October to March during 1928 to 1932 revealed that the parasites develop to the last larval or prepupal stage and remain thus until late February or early March, when they begin transforming to the pupal stage. Some of the parasites are ready to emerge on warm days in the middle of March or, with an early spring, they may emerge sooner. In 1928 *B. fonscolombei* emerged and oviposition was secured on March 18. In 1932, following a warm winter, a specimen emerged February 26. Oviposition usually ceases in early or mid November. A few adults may emerge during December, and occasional specimens have emerged in January.

Jars of blowfly larvae and pupae were carried through the winter of 1928–29, from which emerged 1,308 *B. fonscolombei.* These parasites hibernated for an average period of 168 days, with an extreme for three individuals of 191 days.

Observations and tests show that *Brachymeria fonscolombei* larvae do not overwinter in host larvae but in host pupae. Large numbers of blowfly larvae were parasitized in October, 1928. In November the blowfly pupae were separated from the larvae which had not pupated. *B. fonscolombei* emerged the following spring from the pupae only. This would tend to corroborate the results of Holdaway (*5*), who found parasitization by *Alysia manducator* Panzer to be a stimulus to pupation in Lucilia.

There is no evidence that *B. fonscolombei* overwinters in adult form. Adults have never been observed or collected during midwinter. Numerous experiments have been conducted in which adults were given the opportunity to hibernate in soil, dried meat, wood shavings, and burlap. In every instance the adults sought to escape. They lived only the normal time, about 9.5 days. The greatest longevity recorded was that of one individual which lived 23 days.

HOSTS

While the hosts of *B. fonscolombei* were being studied, precautions were taken that no contaminations of the tests might occur. For the work with *Phormia regina* or *Cochliomyia macellaria*, these being the only representatives of their respective genera occurring at Uvalde, larvae were secured from a pure strain of each species. In each of the other tests the progeny of a single female fly was used. For breeding media, meat was removed from rabbit carcasses immediately after the rabbits were killed. In each test 2 ounces of this meat was placed in a pint Mason jar containing 1½ inches of sand and capped with 60-mesh screen gauze. Ordinarily the female fly was placed within the jar and allowed to oviposit on the meat, although occasionally oviposition was secured in another jar and the eggs transferred. These preliminaries were conducted as quickly as possible under constant observation and within a screened insectary. As soon as the fly was introduced, the jar was placed in a glass-top breeding cage in a fly-proof insectary. This procedure prevented any contamina-

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tion by Sarcophaga or other flies. After the fly eggs had hatched, parasites were placed within the jar. Later both the parent fly and parasites were pinned and saved for further study. The parasitized larvae, after feeding had been completed, pupated in the sand; and, upon emergence, the second generation of flies and parasities were recorded and saved.

LIST OF HOST SPECIES

Brachymeria fonscolombei has been bred from numerous species of Diptera of the familes Calliphoridae, Sarcophagidae, and Muscidae. The following list includes all known authentic host records.

Family Calliphoridae: *Calliphora coloradensis* Hough, *Lucilia sericata* Meig., *L. unicolor* Town., *Phormia regina* Meig., and *Cochliomyia macellaria* Fab.

Family Sarcophagidae: *Sarcophaga plinthopyga* Wied., *S. impar* Ald., *S. haemorrhoidalis* Fall., and *S. carnaria* L.

Family Muscidae: *Synthesiomyia nudiseta* V.d.W.

HOST CASE RECORDS

Calliphora coloradensis Hough.—Uvalde, Tex. March 19, 1930, progeny of single fly (eggs deposited March 17) exposed to parasites. Oviposition continued until March 23. March 15–16, 10 *C. coloradensis* (identified by Laake) emerged; average developmental period 29 days. April 26–May 6, 7 *B. fonscolombei* (identified by Gahan) emerged; average developmental period 37 days.

Lucilia sericata Meig.—Uvalde, Tex. May 17, 1930, progeny of single fly (eggs deposited May 16) exposed to parasites. June 1, about 100 *L. sericata* (identified by Laake) emerged; average developmental period 16 days. June 18, one *B. fonscolombei* emerged; developmental period 30 days.

Uvalde, Tex. September 3, 1931, progeny of single fly (eggs deposited September 1) exposed to parasites. September 15–16, 12 *L. sericata* emerged; average developmental period 18 days. September 21–25, 16 *B. fonscolombei* emerged; average developmental period 20 days.

Lucilia unicolor Town.—Uvalde, Tex. September 3, 1930, progeny of single fly (eggs deposited September 1) exposed to parasites. Parasitization continued until about September 5. September 15–19, 50 *L. unicolor* (identified by Laake) emerged; average developmental period 15 days. September 29, one *B. fonscolombei* emerged; developmental period 25 days.

Phormia regina Meig.—Uvalde, Tex. June 24, 1930, larvae from pure strain of *P. regina* (eggs deposited June 22 from specimens received from North) exposed to parasites. July 6, 107 *P. regina* (identified by Laake) emerged; average developmental period 14 days. July 11–15, 111 *B. fonscolombei* emerged; average developmental period 18 days.

Cochliomyia macellaria Fab.—Uvalde, Tex. August 18, 1921, larvae from egg mass of *C. macellaria* (identified by Parman) deposited August 16 exposed to parasites. September 5–6, five *B. fonscolombei* (identified by Gahan) emerged; average developmental period 18 days. Record by Parman.

Uvalde, Tex. October 6, 1928, lot of about 100 larvae taken from a strain of pure *C. macellaria* were exposed to parasites. Some of the parasites overwintered in the host pupae. November 26, 1928, six *B. fonscolombei* emerged; average developmental period 51 days. March 25–April 1, 1929, five *B. fonscolombei* (identified by Gahan) emerged; average developmental period 174 days.

Sarcophaga plinthopyga Wied.—Uvalde, Tex. July 10, 1929, larvae from single female fly larviposited and placed with parasites. Parasitization continued; July 11 assumed as average date of parasitization. July 30, 20 *S. plinthopyga* (identified by Hall) emerged; average developmental period 20 days. July 31–August 2, 27 *B. fonscolombei* (identified by Gahan) emerged; average developmental period 21 days.

Uvalde, Tex. May 25, 1930, larvae (larviposited May 24) from a single fly exposed to parasites. June 18–20, three *S. plinthopyga* (identified by Hall) emerged; average developmental period 26 days. June 20–24, 65 *B. fonscolombei* emerged; average developmental period 27 days.

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Sarcophaga impar Ald.—Dallas, Tex. August 24, 1928, larvae taken from dead bird, placed on beef, and exposed to parasites. September 13–14, 11 *S. impar* (identified by Laake) emerged. September 13–16, 34 *B. fonscolombei* emerged; average developmental period 22 days.

Sarcophaga haemorrhoidalis Fall.—Reference: Dalla Torre (*1, p. 388*).

Sarcophaga carnaria L.—Reference: Stefani (*13, p. 11–12*).

Sarcophaga sp. Reference: Parker (*9, p. 239*). Parker said: "We have reared *C. fonscolombei* from various species of the genus Sarcophaga living in a larval state in decomposing meat * * *."

Synthesiomyia nudiseta V.d.W.—Uvalde, Tex. August 4, 1930, progeny of single fly (eggs deposited August 2) exposed to parasites. August 16–17, 52 *S. nudiseta* (identified by Aldrich) emerged; average developmental period 15 days. August 22–25, 32 *B. fonscolombei* emerged; average developmental period 19 days.

Although efforts were made to breed *B. fonscolombei* from *Calliphora erythrocephala* Meig. and *Cynomyia cadaverina* Desv., they were unsuccessful. There is little doubt, however, that the parasite will breed in these two species. Attempts to rear the parasite from *Musca domestica* L. and *Ophyra aenescens* Wied. also failed. It is not impossible that *B. fonscolombei* will breed in these two flies.

PREFERENCE FOR HOST

Demonstration has been made, both in breeding tests in the laboratory and in rearing parasites from field collections, that *B. fonscolombei* can be bred in greatest numbers when the host is a species of the genus Sarcophaga. Thirty host tests were made with various species of flies. *B. fonscolombei* was bred in only three tests from Lucilia larvae, whereas eight tests were failures, while during several years of work with the parasite it was bred in only two instances from *Cochliomyia macellaria*.

An experiment was conducted during the summer of 1930 to determine whether *Brachymeria fonscolombei* exhibited any host preference under natural conditions. For this experiment four shelters such as that shown in figure 5, A, were constructed. Each consisted of a wood frame with sides of 8-mesh hardware cloth, and a solid removable lid. The purpose of this shelter, which was made as open as possible, was to protect the bait from the sun and to keep out animals. In each shelter a bait, consisting of two skinned rabbit carcasses, weighing 10 pounds, was exposed. This meat was placed in a tin pan 4 inches deep and set inside a tub which contained 5 inches of sand. The sand furnished a pupating place for larvae that finished their feeding before the end of the exposure period. The tub had a 6-inch band of cup grease smeared around the upper inside rim to prevent larval migrations. The four tests were located about one half mile apart in a pasture and were not disturbed from the time they were started until they were ready to be rebaited. Rabbit carcasses exposed in this manner permitted flies and parasites to work in a natural way. At the time of collection the larvae were separated according to species, and a representative sample taken of each. Figure 5, B, shows various gaged sifters used to separate pupae and larvae from the sand.

Table 2 shows the results from 12 tests made from June, 1930, to August, 1931. In no instance was a parasite bred from *Cochliomyia macellaria* or from *Lucilia* sp. Of the total emergence from Sarcophaga, 21.4 percent was *B. fonscolombei*. Of the original number of

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Sarcophaga larvae, 16.3 percent produced *B. fonscolombei*. The death rate of Sarcophaga from other causes was 23.5 percent, whereas the death rate of *C. macellaria* was only 7.2 percent.

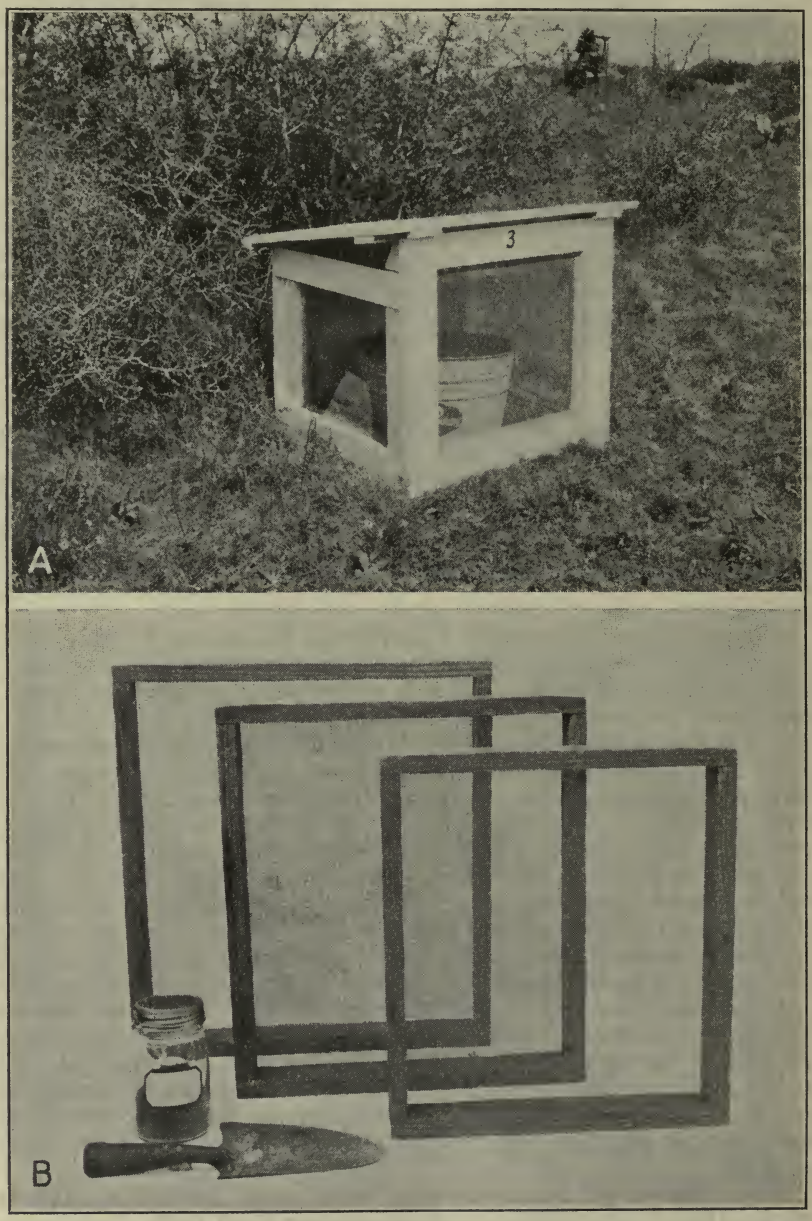

FIGURE 5.—A, Tub containing rabbit carcasses exposed to blowflies and their parasites. The shelter furnished protection against sun, rain, and animals. B, Sifters of 14-mesh screen wire and 6- and 10-mesh hardware cloth used in separating blowfly larvae and pupae from sand.

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TABLE 2.—*Parasites bred from larvae reared from 12 rabbit carcasses exposed under natural conditions, showing host preference of Brachymeria fonscolombei. Uvalde, Tex., June 12, 1930, to Aug. 14, 1931*

Host	Fly larvae reared	Flies emerged	Parasites		Proportion of fly larvae parasitized [1]	Proportion of fly larvae and pupae that died [2]
			Emerged	Proportion of total emergence		
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
Cochliomyia macellaria	1,550	1,439	0	----------	----------	7.2
Sarcophaga sp.	1,550	932	253	21.4	16.3	23.5
Lucilia sp.	700	201	0	----------	----------	71.3
Total or average	3,800	2,572	253	9.0	6.7	25.7

[1] Not including unknown number of parasitized larvae that died.
[2] Not including those that yielded parasites.

THE SCREW-WORM FLY AS A HOST

In two tests only were *Brachymeria fonscolombei* bred from larvae of *Cochliomyia macellaria*, although dozens of exposures were made. In some instances larvae and parasites were confined together in jars, and in other tests large numbers of larvae were collected after having developed naturally in carcasses. In the host-preference tests no Brachymeria were secured from 1,550 *C. macellaria* larvae collected from carcasses where parasites were known to be active. However, numerous observations have been made of the parasite attacking screw worms. On most occasions, when confined together, Brachymeria was seen to oviposit in the maggots.

In October 1931 a study was made to determine the fate of parasite eggs placed in screw-worm larvae. Mature maggots of *C. macellaria* were exposed to *B. fonscolombei* for a single day. On the third day following parasitization, unparastized flies began emerging. Examination of the remaining pupae showed living second-stage larvae of *B. fonscolombei*. In some pupae the parasites, still in the second stage, lived until the seventh day. Below are shown daily records from the test.

October 7, 1931. Mature *C. macellaria* larvae exposed to *B. fonscolombei*. Larvae beginning to pupate.

October 8. Parasite eggs found in larvae which had not pupated.

October 9. Ten puparia opened; no parasites found.

October 11. Flies began emerging from unparasitized pupae. Ten puparia opened; one contained a single second-stage parasite larva, another a small second-stage and a first-stage parasite larva. Each of the flies in the puparia had a well-developed head, thorax, abdomen, legs, antennae, and head and body bristles, but they appeared lifeless. The remaining eight puparia contained living flies.

October 12. Thirty adult *C. macellaria* emerged. Five puparia examined; four contained dead flies and small living second-stage parasite larvae.

October 13. Five puparia examined; one had dead fly only; the remainder contained dead flies, two with single and one with triplet second-stage parasite larvae. The parasites, all living but one (a single), were in each case in the thorax of the fly pupa.

October 14. Five puparia opened; all contained dead flies badly disintegrated; one had twin (one dead) and one had triplet second-stage parasite larvae.

October 16. Ten puparia examined; seven had dead flies, and three had dead flies and dead second-stage parasite larvae. The Brachymeria larvae were brownish, collapsed, and appeared to be rapidly disintegrating.

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October 18. Ten puparia examined; all contained decomposing or mummified flies except two; these had in addition the collapsed remains of Brachymeria larvae.

October 19. Thirty-four remaining puparia opened; all contained mummified flies or decomposed masses.

These observations demonstrate that under certain conditions *Cochliomyia macellaria* larvae are attacked by *Brachymeria fonscolombei* but that both host and parasite meet death. It is probable that, because the life cycle of *C. macellaria* is several days shorter than that of Sarcophaga, the parasite larva does not have sufficient time to complete development before the death of the host brings about destruction of the parasite. In the host-preference tests *C. macellaria* had a death rate of only 7.2 percent during the pupal stage. Under natural conditions, then, the percentage of infestation in this species must be very small.

BRACHYMERIA FONSCOLOMBEI BREEDING IN CARCASSES

The results of collecting blowfly larvae from carcasses and rearing therefrom the flies and parasites indicate that *B. fonscolombei* is more active around small carcasses. This may be due to the fact that Sarcophaga is mostly present in small carcasses, while *C. macellaria* predominates in the larger ones. It appears, therefore, that *B. fonscolombei* is of greatest economic importance in its relation to the blowflies frequenting small carcasses. These are largely Sarcophaga and Lucilia during the warmer months and Phormia, Calliphora, and Sarcophaga during the remainder of the year.

Table 3 shows the results of a number of collections from carcasses of various sizes.

TABLE 3.—*Insects bred from blowfly larvae collected from carcasses of various sizes, 1928–31*

Collection date	Kind of carcass	Size or weight	Fly larvae collected	Flies emerged			*Brachymeria fonscolombei*	
				Cochliomyia macellaria	Lucilia	Sarcophaga	Emergence	Proportion of total emergence
1928			*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
Aug. 17	Horse	Large	1,000	501	--------	--------	--------	--------
Aug. 23	Goat	Medium	1,000	166	5	--------	--------	--------
1929								
June 7	Rabbit	5 pounds	[1] 300	--------	--------	200	93	32
June 27	Rabbit in bait pan of cone trap.	do	[1] 200	--------	3	113	111	49
Aug. 6	Rabbit	do	[1] 100	--------	--------	79	13	14
Aug. 22	Turtle	1 pound	(2)	--------	--------	229	16	7
Oct. 31	Goat	Medium	[1] 10,000	(3)	--------	--------	--------	--------
1930								
May 13	Nestling sparrow	15 grams	(2)	--------	--------	1	93	99
June 17	Sparrow	24 grams	(2)	--------	83	3	12	12
Do	do	do	(2)	--------	175	--------	25	13
June 23	5 goats	Medium, 5 together.	[1] 10,000	(3)	--------	--------	--------	--------
Sept. 5	Goat	Medium	[1] 1,000	(3)	--------	--------	--------	--------
1931								
July 17	Redbird	50 grams	(2)	--------	28	5	18	35
July 20	Fish head	1 pound	(2)	--------	109	53	173	52
Aug. 23	Cow	Large	400	346	--------	--------	--------	--------
Sept. 2	do	do	300	268	--------	--------	--------	--------

[1] Approximate. [2] All. [3] Many.

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These results are corroborated by those shown in table 2, in which Brachymeria were secured in 12 tests where two rabbit carcasses (10 pounds) were exposed. Several thousand 4-ounce meat baits have been exposed in pint jars; *B. fonscolombei* worked readily in bait of this size.

ARACHNID AND INSECT ENEMIES OF BRACHYMERIA

Two instances have been recorded of the spider *Phidippus carolinensis* Peckham preying upon *B. fonscolombei* (Uvalde, Tex., July 24, 1930, and Sept. 21, 1931). While numerous parasites may be caught by this and other species of spiders, the total effect on the species is probably negligible.

Several *B. fonscolombei* placed in cages with *Stagmomantis carolina* Johan. were readily captured and eaten, but it is unlikely that many of these parasites fall prey to this mantid in nature.

No secondary parasites of *B. fonscolombei* have been demonstrated, though several common pupal parasites of Diptera may act as such. Tests made that allowed *Mormoniella vitripennis* (Walk.) to parasitize Sarcophaga pupae already containing *B. fonscolombei* failed to give an emergence of either the parasites or the host. These tests, however, were not extensive.

THE ABUNDANCE OF BRACHYMERIA FONSCOLOMBEI AND ITS IMPORTANCE AS A FACTOR IN BLOWFLY CONTROL

From April through October *B. fonscolombei* is abundant and can be observed wherever small baits are exposed. In many instances more than 200 *B. fonscolombei* have emerged from larvae produced in a 4-ounce piece of meat. During the years 1929, 1930, and 1931 (from April through September), 1,880 4-ounce meat baits were exposed. From larvae produced in these baits were reared 22,639 *B. fonscolombei*, 35 percent of the emergence of flies and parasites.

At Menard, Tex., in 1930, an average of 6.5 percent of the emergence from meat baits was *B. fonscolombei*, with a maximum average emergence from one series of exposures of 25 percent. In the same area during 1931 there was an emergence of 12 percent *B. fonscolombei*. At Brownsville, Tex., during 1930, 9 percent of the emergence from meat baits was *B. fonscolombei*.

It should be distinctly understood that the emergence figures of *B. fonscolombei* from 4-ounce meat baits are presented merely as an indication of the activity of this parasite and not as the exact extent of its effect on blowflies. However, it is interesting to observe that the percentage of emergence is about the same as that secured from small carcasses.

Consideration has been given to the possible effect *B. fonscolombei* might have upon such important Diptera as *Sarcophaga kellyi* Ald., which parasitizes grasshoppers. There are no records of *B. fonscolombei* having been reared from dipterous larvae secured from grasshoppers, although there are several records in which *B. coloradensis* Cress. is mentioned. *Brachymeria fonscolombei* is present in Kansas and Oklahoma, and if it greatly affects these Saracophaga, some mention of it would have appeared in published records before now.

At Uvalde about 33 percent of the maggots that mature in small carcasses not containing larvae of *C. macellaria* are infested with

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B. fonscolombei. Table 3 shows small-carcass infestations ranging from 7 to 99 percent. When *C. macellaria* is included, the percentage of parasitization of matured maggots is about 9 percent. Therefore, in relation to the flies which infest small carcasses and in so much as they affect the total fly population, this parasite is of considerable importance. Its effect on the screw-worm fly, *C. macellaria*, however, is small, and it offers little promise in the control of this species.

SUMMARY

Brachymeria fonscolombei (Dufour), the larval parasite of blowflies, is well distributed over Europe and North America and has been found in Asia. The female parasite pierces the host larva and deposits the egg therein. The egg hatches on the third day, and the larva moves freely about in the body cavity. In warm weather the larva matures in 8 to 12 days. During this time the host larva pupates. After the parasite has destroyed the contents of the host puparium, it in turn pupates. The pupal stage lasts about 10 to 12 days.

The preoviposition period may be very brief, oviposition under ideal conditions occurring on the first day of adult existence. Although several eggs are often deposited in the host, this is a solitary parasite, and only one larva reaches maturity. A few more females than males are produced, about 57 percent females to 43 percent males. Parthenogenetic reproduction may also occur.

The developmental period from egg to adult requires an average of 21 days at a mean temperature of 86° to 90° F. With decreased temperatures this period increases, until at 65° the average developmental period is 35 days. At lower temperatures a portion of the brood overwinters as last-stage larvae in the host pupae. Eight generations may occur at Uvalde, Tex., a portion of the eighth overwintering.

Without food or water, at 70° to 79° F., adults of *B. fonscolombei* live about 3.6 days. Increased temperatures shorten this period. When bananas and water were furnished, the longevity was increased to 4.5 days. Honey, as a food, extended the period to 11 days.

Brachymeria fonscolombei is most active as a parasite of Sarcophaga. However, it readily parasitizes Synthesiomyia and Phormia and was frequently bred from Lucilia and Calliphora. The parasite was rarely secured from the screw worm, *Cochliomyia macellaria* Fab., and it was demonstrated that when *B. fonscolombei* parasitizes this species both insects ordinarily meet death.

B. fonscolombei is found breeding in fly larvae in carcasses of birds, rabbits, turtles, and other small animals. At Uvalde about one-third of the larvae in small carcasses are parasitized, though in numerous cases a much greater degree of parasitization was secured.

Although *B. fonscolombei* appears to be of little promise in controlling the screw-worm fly, it should, because of its habit of attacking fly larvae in small carcasses which easily escape man's attention, be of value, if used in conjunction with some parasite of *C. macellaria* and with other insect enemies of blowflies, to form a parasite-predator combination for reducing the blowfly population.

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LITERATURE CITED

(1) Dalla Torre, K. W. von
1898. CATALOGUS HYMENOPTERORUM HUCUSQUE DESCRIPTORUM SYSTEMATICUS ET SYNONYMICUS. v. 5, 598 p. Lipsiae.

(2) Dalman, J. V.
1921. FÖRSÖK TILL UPPSTÄLLING AF INSECT-FAMILJEN PTEROMALINI (CYNIPSEAE LATR.) I SYNNERHET MED AFSEENDE PÄ DE I SVERIGE FUNNE ARTER. Svensk. Vet. Akad. Handl. 41:143.

(3) Dufour, L.
1841. DES METAMORPHOSES DES CHALCIS, ET DESCRIPTION D'UNE ESPÈCE PEU CONNUE DE CE GENRE D'HYMÉNOPTÈRES. Ann. Soc. Ent. France 10:11–19, illus.

(4) Gahan, A. B., and Fagan, M. M.
1923. THE TYPE SPECIES OF THE GENERA OF CHALCIDOIDEA OR CHALCID-FLIES. U.S. Natl. Mus. Bul. 124, 173 p.

(5) Holdaway, F. G., and Evans, A. C.
1930. PARASITISM A STIMULUS TO PUPATION; ALYSIA MANDUCATOR IN RELATION TO THE HOST LUCILIA SERICATA. Nature (London) 125: 598–599.

(6) Masi, L.
1909. CONTRIBUZIONI ALLA CONOSCENZA DEI CALCIDIDI ITALIANI. SPECIE DEL GENERE CHALCIS FABR. Bol. Lab. Zool. Gen. e Agr. Scuola Super. Agr. Portici 3:106–110.

(7) ———
1916. MATERIALI PER UNA FAUNA DELL'ARCIPELAGO TOSCANO. CALCIDIDI DEL GIGLIO. Ann. Mus. Civico di Storia Nat., Genova 47 (ser. 3, v. 7):[54]–122, illus.

(8) Mercet, R. G.
1923. LOS CALCIDIDOS PARÁSITOS DE ORUGAS. Rev. Fitopatologia 1:12–19, illus.

(9) Parker, H. L.
1923. CONTRIBUTION À LA CONNAISSANCE DE CHALCIS FONSCOLOMBEI DUFOUR (HYM.). Bul. Soc. Ent. France 1923:238–240.

(10) ———
1924. RECHERCHES SUR LES FORMES POST-EMBRYONNAIRES DES CHALCIDIENS. Ann. Soc. Ent. France 93:[261]–379, illus.

(11) Rossi, P.
1807. FAUNA ETRUSCA, SISTENS INSECTA QUAE IN PROVINCIIS FLORENTINA ET PISANA PRAESERTIM COLLEGIT PETRUS ROSSIUS. CXVI. CHALCIS. v. 2, p. 86–89. Helmstadii.

(12) Ruschka, F.
1922. CHALCIDIDENSTUDIEN. DIE EUROPÄISCHEN ARTEN DER GATTUNG CHALCIS FABR. Konowia, Ztschr. systematische Insektenkunde 1:221–233.

(13) Stefani, T. de
1889. UNA NOTA SULLA CHALCIS DALMANNI, THMS. Nat. Siciliano 9:11–12.

(14) Westwood, J. O.
1832. DESCRIPTIONS OF SEVERAL NEW BRITISH FORMS AMONGST THE PARASITIC HYMENOPTEROUS INSECTS. London and Edinburgh Phil. Mag. and Jour. Sci. (3) 1:127–129.

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TECHNICAL BULLETIN No. 366 JULY 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

FURTHER INVESTIGATIONS OF THE PARASITES OF POPILLIA JAPONICA IN THE FAR EAST

By C. P. CLAUSEN, *senior entomologist*, H. A. JAYNES, *associate entomologist*, and T. R. GARDNER, *associate entomologist, Division of Japanese and Asiatic Beetles, Bureau of Entomology* [1]

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INTRODUCTION

In a previous publication (*6*)[2] an account was given of the investigations on *Popillia japonica* Newm. and its natural enemies in Japan and Chosen (Korea) during the years 1920–1923, inclusive. The present account covers the work of the following 5-year period (1924–1928, inclusive) and supplements the above-mentioned publication, presenting additional information relative to the parasites previously listed, as well as accounts of other species found attacking the genus Popillia.

[1] The authors acknowledge particularly the assistance of L. B. Parker, who was assigned to the work in India in 1927; K. Sato, assistant in Japan since 1921; Y. Ouchi, S. Fujii, and Y. Hasegawa. D. B. Langford assisted in the field work in Japan during several seasons. During the progress of the investigations in Japan, Chosen, China, and India the authors received great assistance from the various Government officials. S. I. Kuwana, chief of the Imperial Plant Quarantine Service of Japan, offered every facility for the work in that country. The director and staff of the Chosen Agricultural Experiment Station have kindly provided laboratory facilities at Suigen each season since 1924. The work in China was greatly facilitated through aid extended by Y. Hsuwen Tsou, vice director of the Chinese Bureau of Entomology, and his associates at the National Southeastern University at Nanking, and also by A. W. March, biologist at the Hangchow Christian College, and the authorities of that college, through the provision of laboratory facilities. To T. Bainbrigge Fletcher, Imperial entomologist of India, the senior author is much indebted for valuable advice regarding entomological conditions in India relating to the project, for the determination of Indian insect material, and for the use of the entomological library at the Agricultural Research Institute at Pusa.

[2] Italic numbers in parentheses refer to Literature Cited, p. 57.

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In Japan and Chosen the collection work was continued very much along the lines previously described, with some added investigations upon the parasites of *Anomala orientalis* Waterh., *Autoserica castanea* Arrow, and *Serica similis* Lewis, three additional Asiatic pests found to have become established in the eastern part of the United States during recent years.

The work in China (fig. 1) was initiated by J. F. Illingworth in the fall of 1923 and continued through 1924, when it was taken over by H. A. Jaynes and developed until its abandonment at the end of 1926, the unsettled political conditions in that country making its further continuation impracticable. A portion of the work on Tiphia, however, was continued for the following two seasons in conjunction with that in Japan and Chosen.

The field of investigation in China centered at Shanghai, and extended over the coastal district from Peiping (Peking) southward to Amoy and Foochow, although some scouting was done in the Yangste Valley as far inland as Ichang. The main centers of parasite collection and rearing were in the outlying districts about Shanghai and Foochow.

The Indian investigations (fig. 2) were restricted very largely to the Khasi Hills in Assam, headquarters being at Shillong. This location was chosen, at the time the investigations were initiated, upon the advice of T. Bainbrigge Fletcher, Imperial entomologist of India, and proved exceptionally well suited for this project on account of the abundance of several species of Popillia and certain of their parasites.

In addition to the main fields of investigation, observations were made in Taiwan (Formosa), the Philippine Islands, Java, Malaya, Burma, and Ceylon. Of these, the only ones seeming to offer possibilities for future work are Taiwan and the Philippine Islands.

THE PARASITES AND THEIR BIOLOGY

During the course of the investigations in Japan, Chosen, China, and India the following parasites were studied with a view to their utilization in the control of *Popillia japonica* in the United States. Those species preceded by an asterisk are, under normal field conditions, parasitic upon *P. japonica* itself, whereas the remaining species listed attack other members of the genus Popillia.

	Countries
Parasites of the adult beetle:	
Tachinidae:	
**Centeter cinerea* Ald	Japan.
**Eutrixopsis javana* Towns	Japan.
**Hamaxia incongrua* Walk	Japan, Chosen, China, India.
**Pexomyia genalis* Ald	Japan.
**Trophops clauseni* Ald	Japan.
Pyrgotidae:	
Adapsilia flaviseta Ald	India.
Parasites of the larva:	
Dexiidae:	
Dexia ventralis Ald	Chosen.
**Prosena sibirita* (Fab.)	Japan, Chosen, India.
Scoliidae:	
Tiphia assamensis A. and J	India.
Tiphia clauseni A. and J	India.
Tiphia communis A. and J	China.
Tiphia matura A. and J	India.
Tiphia notopolita A. and J	Japan, Chosen, China.
**Tiphia popilliavora* Roh	Japan, Chosen, China.
Tiphia vernalis Roh	Japan, Chosen, China.
Tiphia sp	Taiwan.

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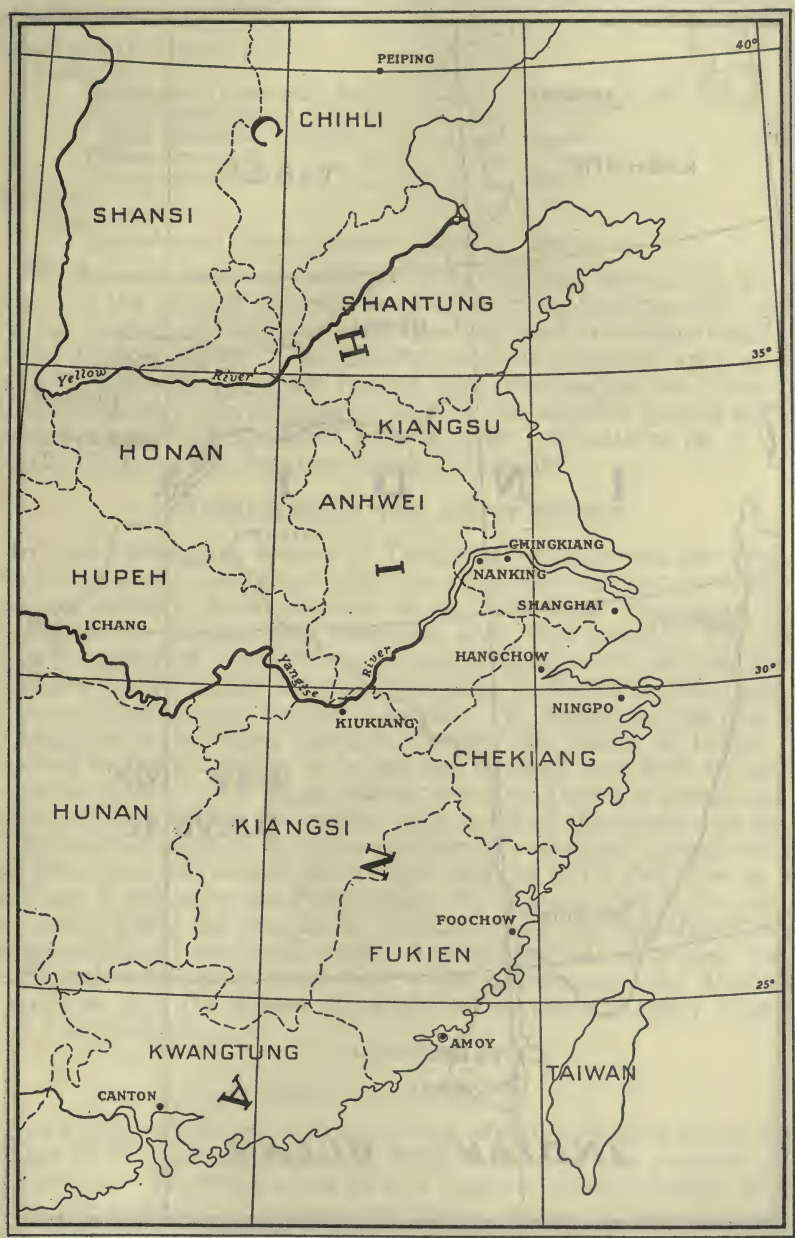

FIGURE 1.—Map of part of China showing the main areas in which investigations on parasites for *Popillia japonica* were carried on.

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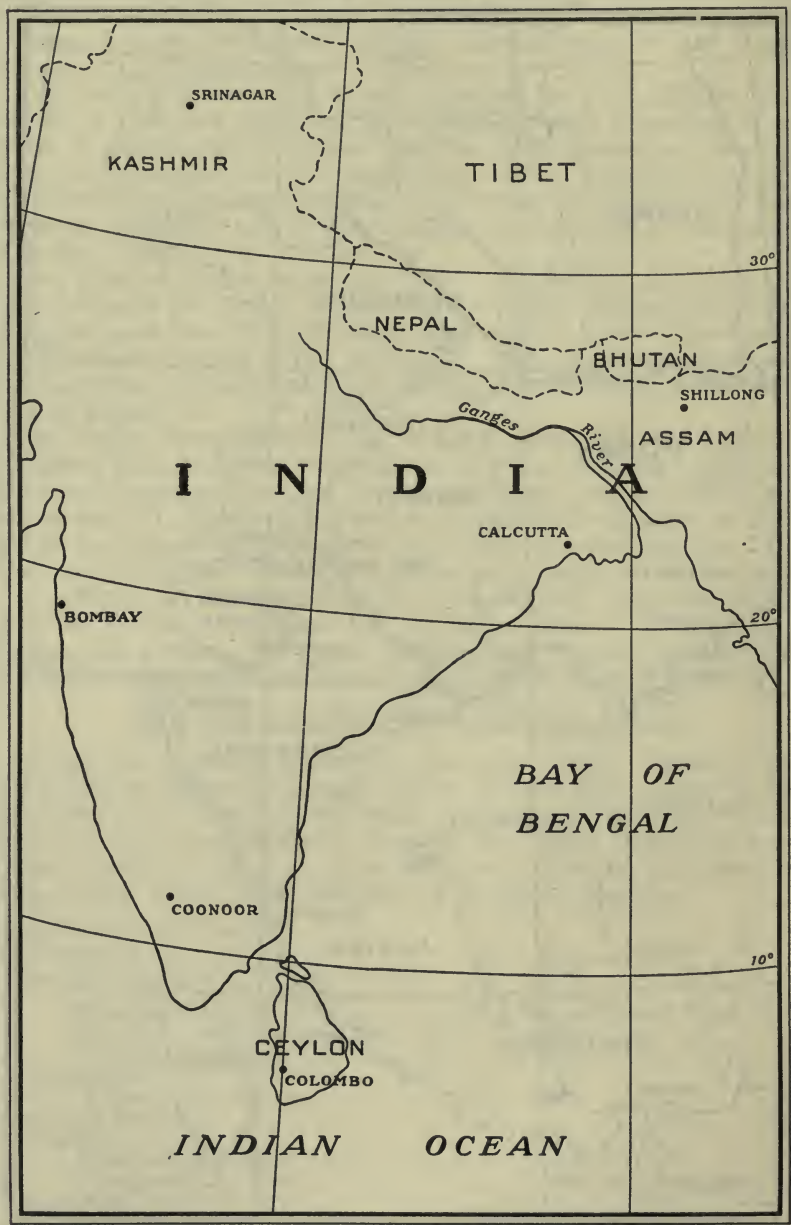

FIGURE 2.—Map of India showing the main areas in which investigations on parasites for *Popillia japonica* were carried on.

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In addition, the following species, which normally attack related genera, have been found to be, to a greater or less degree, adaptable to *P. japonica*, and shipments for utilization against that pest have been made:

Parasites of the larva:
- Scoliidae:
  - *Campsomeris annulata* (Fab.) ---------- Japan, Chosen, China.
  - *Tiphia brevilineata* A. and J ---------- Chosen.
  - *Tiphia biseculata* A. and J ---------- Japan.
  - *Tiphia koreana* Roh ---------- Chosen.
  - *Tiphia pullivora* A. and J ---------- India.

Predators:
- Carabidae:
  - *Craspedonotus tibialis* Schaum ---------- Japan.

This bulletin deals only with the investigations bearing on the discovery of the various natural enemies, their life histories and habits, and the rearing and shipping methods employed in transporting them to the United States. The manner of their handling upon arrival in the United States, their rearing and colonization, and the field distribution and effectiveness of such of the parasite species as have become established, are dealt with in other publications (*2*, *4*, *9*, *10*, *11*, *12*, *13*) from the Japanese beetle laboratory.

PARASITES OF THE ADULT BEETLE

In Japan alone five species of Tachinidae parasitic on the adult of *Popillia japonica* were found, and the attack on other groups of Scarabaeidae, notably the Rutelinae, is very nearly as extensive. It is of interest to contrast this condition with that found in the other fields investigated. In Chosen *Hamaxia incongrua* is the sole representative of the family attacking Popillia, but several other species occur on other genera, notably Anomala. *H. incongrua* was found in all sections, from Japan through Chosen and China to India. As opposed to the condition in Japan and Chosen, and with the single exception noted, not a single species was found on any scarabaeid in China or India during the several years in which the search was made. In the coastal districts of China the adult beetles are almost entirely free from parasite attack of any sort, and in India the place of the tachinids is taken by the Pyrgotidae. It appears that, in the Asiatic regions at least, the groups of Tachinidae having scarabaeid hosts are essentially of temperate rather than subtropical or tropical habit. In general it has been noted that, where these occur, the dispersion is uniform, and the degree of parasitization remains fairly constant from year to year.

TACHINIDAE

CENTETER CINEREA ALD.

The biology of *Centeter cinerea*, a very effective parasite of the adult beetles of *P. japonica*, was quite fully covered in the previous publication (*6*). The work of the next 5 years consisted largely in the continued collection of parasitized beetles and the shipment of additional quantities of puparia for establishing new centers of dispersion, and in strengthening certain of the colonies already established in the United States.

In general, the high rate of parasitization in the field in northern Japan, with its biennial fluctuation due to the partial 2-year life

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cycle of the host, has been maintained in spite of the very large numbers of parasitized beetles collected in that section during the last 8 years. Observations in 1927 indicated a parasitization of 47.9 percent of the beetles present from July 15 to 24—a higher percentage than was recorded in 1921 and 1923, corresponding years in the biennial cycle.

The more recent investigations on the distribution of Centeter in Japan have extended its known southern range much beyond that previously recorded, it now being known to occur in several localities in the Tokyo-Yokohama district. When collections of Hamaxia were being made in 1924 at Utsunomiya, about 50 miles north of Tokyo, 20 percent of the beetles taken along the borders of certain wooded areas during the latter part of June bore eggs of Centeter. A small proportion, less than 1 percent, in the Tokorozawa and Narashino districts near Tokyo bore eggs of Centeter in 1928, but a small lot secured June 26 at Hashimoto, about 20 miles west of Yokohama, showed a parasitization of 21 percent. These beetles were dissected, and the stage of development of the larvae contained in them showed that the first oviposition must have taken place about June 20. This is approximately 1 month earlier than oviposition at Sapporo and is correlated with the corresponding advance in the time of emergence of the host. This correlation is rather noteworthy in view of the apparent failure of the species to adapt itself to a corresponding change in the time of appearance of the host in the United States.

SUPERPARASITISM AND EGG DISTRIBUTION

In view of the high percentage of parasitization effected by this species and the extensive superparasitization which unavoidably results therefrom, the determination of whether or not the female Centeter exercises any choice of hosts, avoiding if possible those which already bear eggs, is of interest and importance. A conclusion in this respect cannot be reached by direct observational methods, either in the field or in the laboratory, but it is capable of solution by the analysis of data from series of field-collected beetles showing varying percentages of parasitization and a consequent variation in the proportion of parasite eggs lost through superparasitization.

Curve A in figure 3 shows the percentage of parasitization attained if duplicate oviposition is entirely avoided. In this case the deposition of 100 Centeter eggs on a colony comprising a like number of beetles would result in a parasitization of 100 percent. This very evidently does not occur. Curve B shows the number of eggs which would need to be deposited on the 100 hosts to attain different percentages of parasitization provided chance alone governed the placement of the eggs.[3] It is seen that, to secure a parasitization of 50 percent, the deposition of 70 eggs is necessary, and for 60 percent, 90 eggs. The increase of the percentage of parasitization beyond this point involves the wastage of an ever-increasing proportion of eggs, and the number deposited must be increased to 220 to effect a 90 percent parasitization.

As compared with curve B, representing the result under the law of chance occurrence alone, there is indicated by dots a series of 11 counts

[3] Fiske (*8*) gives an extended discussion of chance occurrence as it relates to superparasitism, and the curves of figure 3 are taken from his illustration. The dots are from the records of the authors of the present bulletin.

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of the actual number of eggs borne by beetles collected in different localities, and the percentages of parasitization indicated. Each count represents from 200 to 1,000 beetles, and the egg number is the ratio to 100 beetles. It is seen that one of the field records falls on the curve of chance occurrence, and that all others fall below the curve.

Had the females shown any preference for unparasitized beetles as against those already bearing eggs or containing larvae, the points plotted would have been between curves A and B rather than below curve B. The fact that they are below this line, however, is not interpreted as indicating any actual preference for beetles already parasitized, but is attributed instead to the fact that those already parasitized, and in which the Centeter larvae have reached the intermediate stage of development, are more sluggish than healthy beetles and consequently offer less resistance to the oviposition efforts of the

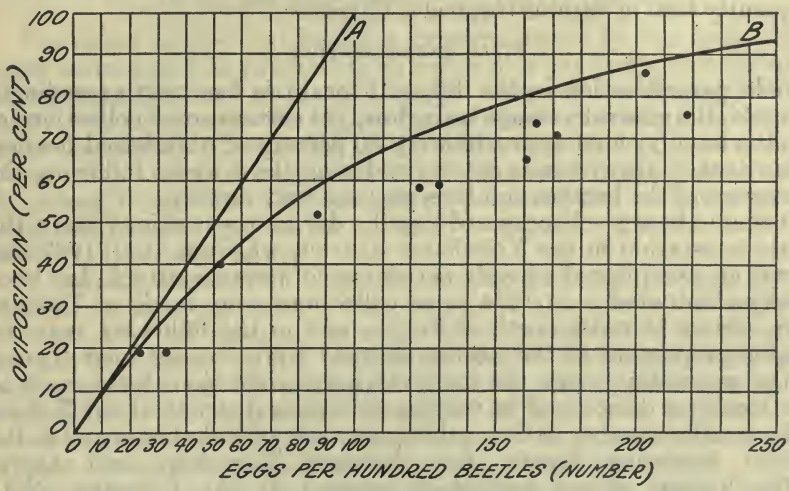

FIGURE 3.—Oviposition by *Centeter cinerea* upon Japanese beetles in the field as compared with the curve of chance occurrence: A, The theoretical result where superparasitism is entirely absent; B, the theoretical result with oviposition governed by chance alone. The dots represent actual field counts of eggs of *C. cinerea* on *Popillia japonica*.

parasite. It is evident, however, that Centeter exercises no discrimination in the choice of hosts, and that the deposition of the eggs is very probably governed by chance alone.

SHIPMENTS

Large numbers of parasitized *P. japonica* beetles have been collected, and the puparia secured from them shipped to the United States each year since 1920, with the exception of 1925 and 1926. The total number of beetles thus collected to the end of 1928 was 603,495, and the puparia obtained therefrom, representing approximately 85 to 90 percent of this number, were forwarded.

There has been little modification in the methods of rearing and packing from those previously employed, or in the care of the shipments en route. Greater care, however, has been taken to eliminate the bodies of dead unparasitized beetles before shipment, thus reducing the amount of decomposition gases generated in the cases during transit.

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Hamaxia incongrua Walk. (Ochromeigenia ormioides Towns.)[4]

In spite of continued experimentation it has not yet been possible to establish by actual observation the exact manner in which *Hamaxia incongrua* attacks its host and in which entrance is effected into the body by the primary larva. Further records have been obtained, however, on development, host relationships, and the extent of field parasitization in the various countries included in this investigation.

The rearing records now available show Hamaxia to have been secured from the following hosts: *Popillia japonica*, *Anomala rufocuprea* Motsch., *A. orientalis*, and *Adoretus tenuimaculatus* Waterh. in central Japan; *Popillia castanoptera* Hope, *P. chinensis* Friv., *P. cyanea* Hope, *P. mutans* Newm., and *P. pustulata* Fairm. in China; and *P. cupricollis* Hope and *P. cyanea* in India. The species is widely distributed throughout the Asiatic and Malayan regions, and it is frequently seen in various tropical countries.

FIELD PARASITIZATION

Field parasitization in the different localities has been exceedingly variable, the general average being low, yet certain small collections of Popillia have yielded approximately 50 percent of parasitized beetles. The attack is always most extensive during the 3 weeks following the emergence of the beetles, and then declines very rapidly.

Owing to heavy collections of Popillia during the previous years, the beetle infestation in the Yokohama district, which in 1921–1923 had shown an exceptionally heavy percentage of parasite attack, has been largely eliminated. In 1924 some collections were made at Utsunomiya, about 75 miles north of Tokyo, and in the following year the greater proportion of the beetles shipped were secured near Kyoto. In the succeeding years the most extensive collections were made in new localities discovered in various suburban districts about Tokyo, and a smaller number in the outlying districts of Yokohama and in the district bordering Sagami Bay, between Kamakura and Akiya.

The highest actual emergence secured at the Riverton, N.J., laboratory from any of the seasons' shipments was that occurring in 1926, when 3.62 percent of the beetles in four consignments, comprising a total of approximately 25,297, collected in the Tokyo-Yokohama section, yielded living flies. Rearings of relatively small lots at the Yokohama laboratory from beetles collected in localities especially favorable for the parasite gave a much higher percentage. The heaviest parasitization was found in the districts immediately south of Yokohama, where collections at Akiya in 1927 showed 17.14 percent of the beetles attacked, while at Sugita in the same year two lots collected on June 23 and 27 showed a parasitization of 14.2 and 24.6 percent, respectively. A small quantity secured at Hashimoto, about 20 miles west of Yokohama, yielded parasite puparia from 41.2 percent of the beetles, and 1,470 beetles collected at Narashino July 11, 1928, showed a parasitization of 33.1 percent. In the districts about Yokohama the general parasitization of Adoretus during this period was found to be 13.3 percent. The heavier attacks by Hamaxia were almost invariably found to occur in rather hilly places with a fairly dense undergrowth, and where beetle feeding was restricted or centered largely upon a rather limited number of favored food plants.

[4] In the previous publications on the parasites of *Popillia japonica* this species was listed under the name *Ochromeigenia ormioides* Townsend, but this has recently been placed as a synonym of *Hamaxia incongrua* Walk., by Townsend, who examined Walker's types in London.

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Investigations on the western side of Honshu, where beetles are common but the climate is much colder, showed Hamaxia to be present in very small numbers. No indication of the parasite was found at Toyama and Niitsu, while 0.9 percent of the beetles collected at Nagaoka and only 1 in 250 examined at Tsuruga were parasitized.

In Chosen, China, and India Hamaxia is a very uncommon parasite on the species of Popillia occurring there, and not a single record has been secured showing parasitization as high as 1 percent—in fact only occasional individuals were reared from the several million beetles collected. Though the species is of very wide distribution, its effectiveness seems to be limited to the warmer temperate regions, and there it is of value under special conditions markedly different from those under which the beetle assumes the status of a serious economic pest in the United States.

NOTES ON THE LIFE HISTORY OF HAMAXIA INCONGRUA

The death of the host beetle is brought about by the early third-stage larva 6 or 7 days after its entrance into the body, and pupation occurs about 3 days later. The pupal stage of the first generation lasts 11 to 13 days at the higher temperatures prevailing during late June and July. Emergence of the adult from the puparium takes place almost exclusively between 6 p.m. and midnight—a habit doubtless related to the crepuscular or nocturnal activities of the adult, and in contrast to the morning emergence of most, if not all, parasites of diurnal habit.

A variable majority of Hamaxia develop in female beetles, though not nearly so pronounced a majority as in Centeter. As the larviposition habit of Hamaxia is unknown no explanation can be given for this condition. It has been noted that a considerable number of beetles remain on the foliage of the food plants until late in the evening, and the proportion of these of each sex may determine the relative extent to which they are attacked. In Adoretus the number of each sex attacked was found to be approximately equal.

Laboratory experiments were repeatedly made in the attempt to secure mating and larviposition, but so far as could be determined, mating did not occur in a single instance under the conditions provided. Females were found to contain from 300 to 350 apparently mature eggs in the ovaries within 10 days after emergence, after having been confined with males for the greater portion of that time, yet none of the eggs had descended into the ovisac and consequently no embryonic development had taken place.

The exact number of generations of Hamaxia is uncertain, though there are certainly two and possibly a third, if hosts are available. The first is on Popillia and Adoretus and is numerically much the largest; the following one is on Adoretus and Anomala, owing to the virtual disappearance of Popillia by the time the second brood of females is ready for larviposition. In the investigations in Chosen, particularly where extended adult collections could be made by sweeping, it was found that a considerable number of females were in the field during the latter half of September and in early October, when it was rather cool and no host beetles of any species were available for attack. There is, consequently, a possibility that a portion of the Hamaxia population may pass the winter in the adult stage.

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THE SECOND-STAGE LARVA

In the previous publication (*6*) the various stages, with the exception of the second larval instar, were described and figured. This instar is shown in figure 4, with details of distinguishing characters.

Description: Length approximately 2.5 mm, color white. Body broadest in the caudal region, with the last segment broadly bilobed and swollen ventrally. Derm finely striate at margins of segments, as shown in figure 4, B. Posterior spiracles widely separated, each having a dorsally directed hook the surface of which is wrinkled transversely (fig. 4, E). Mouth parts as in figure 4, C and D.

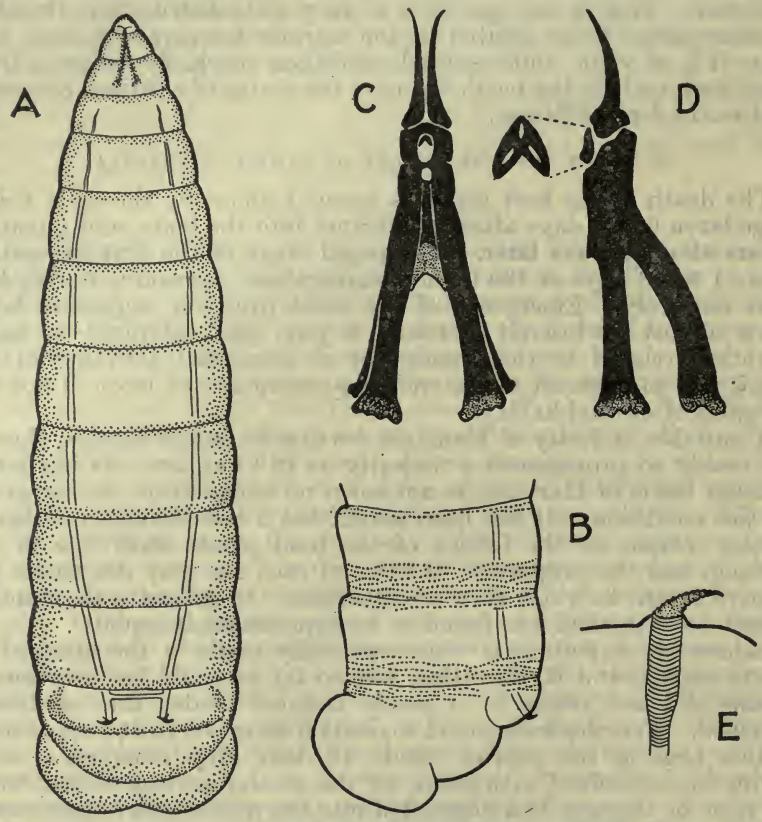

FIGURE 4.—Second larval instar of *Hamaxia incongrua:* A, dorsal view, ×45; B, lateral view of caudal segments, ×45; C and D, the mouth hooks; E, lateral view of caudal spiracle.

SHIPMENTS

During the period from 1923 to 1928, inclusive, a total of 298,000 adult beetles of *Popillia japonica* were collected and shipped alive to the United States for the rearing of Hamaxia. Methods of handling were similar to those previously used, except that refrigeration for any portion of the journey was abandoned, as the condition upon arrival was found to be much better in the case of material kept under normal temperatures.

EUTRIXOPSIS JAVANA TOWNS.

The records of *Eutrixopsis javana* as a parasite of the adult of *Popillia japonica* are based upon the emergence of 210 flies of this parasite in 1923 from the shipments of Centeter forwarded from

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Sapporo, Japan, in 1922, and of 78 in 1928 from the shipments in 1927 from the same locality.

In 1928 a particular effort was made to secure further information relative to this species. Through examination of the beetles bearing tachinid eggs, brought in by the collectors, it was anticipated that the egg of this species, if the egg is laid rather than a living larva, would differ sufficiently either in appearance or position on the host to be distinguishable from that of Centeter. However, no information was secured by this means. The later examination of the dead parasitized beetles, and of the puparia contained within them, revealed only Centeter and a small proportion of a sarcophagid scavenger.

Large quantities of beetles free from external tachinid eggs were also set aside and later examined for puparia, but with negative results. More than 100,000 beetles were thus examined, and not a

FIGURE 5.—*Trophops clauseni*, adult female, × 7. (Drawing by Y. Hasegawa.)

single Eutrixopsis puparium was found. It is evident that the species is of no consequence as a factor in the control of the host in its native habitat.

PEXOMYIA GENALIS ALD.

The parasite *Pexomyia genalis* was described by J. M. Aldrich on the basis of a small number of adults reared at the Riverton laboratory from adult Popillia collected in central Japan in 1925 and shipped for rearings of Hamaxia. Since that time it has not been encountered in the work in Japan, and nothing is known as to its habits other than that at least two generations a year develop, as indicated by the emergence of the adults in late July from beetle collections made during the latter part of June.

TROPHOPS CLAUSENI ALD.

In an examination of 3,000 beetles collected at Tokorozawa, near Tokyo, Japan, in late June 1928, 1.2 percent were found to be parasitized by tachinid larvae readily distinguishable from those of

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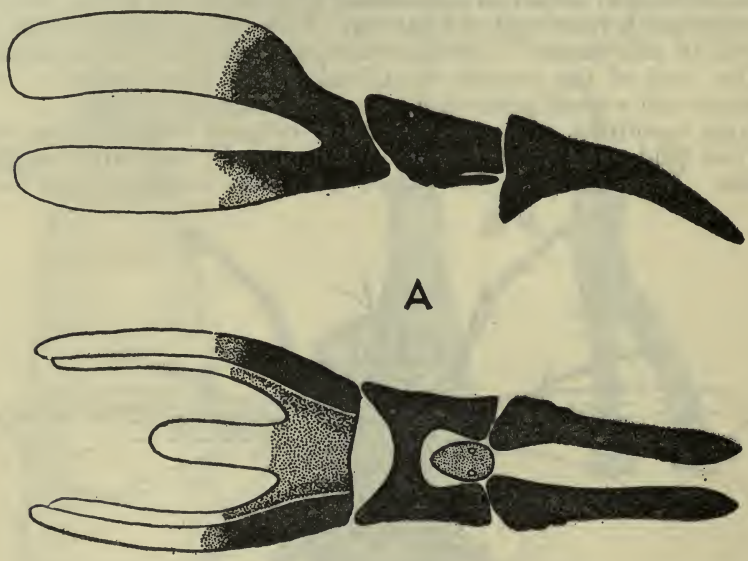
Hamaxia and Centeter, which were also included in this host material. Beetles collected a week later did not contain a single individual. Adults have since been secured and described under the name *Trophops clauseni* by Dr. Aldrich.

An examination of the beetles containing these larvae showed them in every case to be free from external tachinid eggs; consequently it



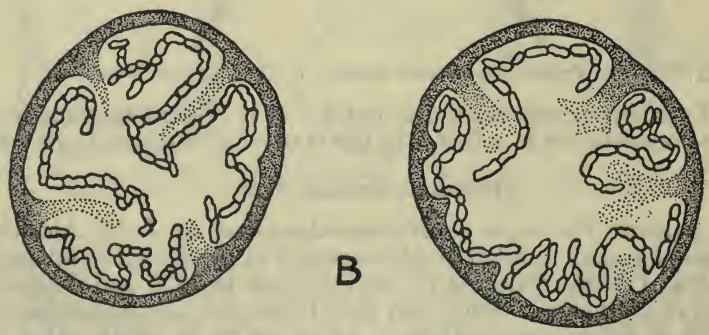


FIGURE 6.—Final larval stage of *Trophops clauseni:* A, Mouth hooks; B, caudal spiracles.

may be assumed that Trophops deposits living larvae much after the manner of Hamaxia. The period of larval development in the host body is longer than that of Centeter and Hamaxia, the maximum period from the collection of the beetles to the pupation of the parasite being 12 days, presumably covering the whole period, as compared with the 9 or 10 days of Hamaxia. The pupal stage lasts approximately 20 days.

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The adult female of Trophops is shown in figure 5, and figure 6 shows the mouth hooks (A) and the posterior spiracles (B) of the mature larva, for comparison with those of other tachinids found in the adult beetles. The larval characters serve readily to distinguish the species from Centeter and Hamaxia, the spiracles being sessile, much larger than in Centeter, and closely set together.

PYRGOTIDAE

Adapsilia flaviseta Ald.

FIELD OBSERVATIONS

The first indications of parasitization of Popillia by *Adapsilia flaviseta* were found in a small quantity of beetles collected August 16, 1925, in a forested area a few miles from Shillong, India. The dis-

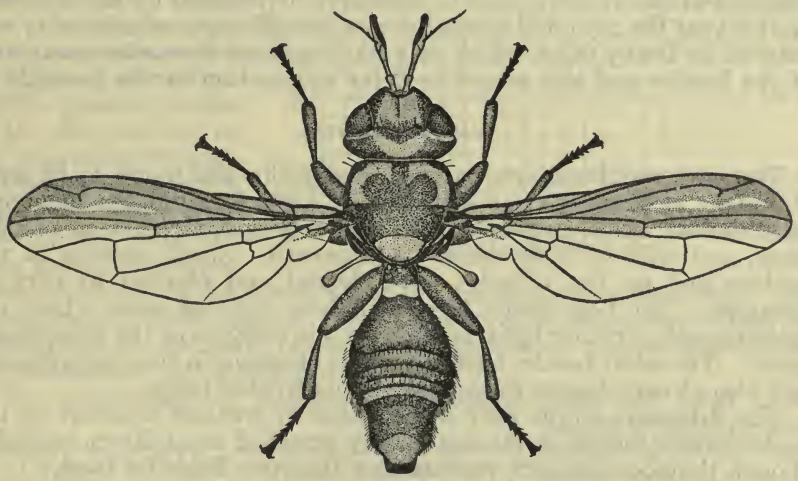

FIGURE 7.—*Adapsilia flaviseta*, adult female, × 6.

section of these beetles revealed that a few of them contained parasitic dipterous larvae quite distinct in form from any of the Tachinidae previously studied in Japan. No adults could be found in the field, but the distinctive central depression or cavity in the last abdominal segment indicated it to be of the family Pyrgotidae. A search in the locality of collection failed, however, to reveal adults of the family at this time. A total of 81,000 beetles (*Popillia cupricollis*) were collected during the period from August 17 to September 20, but from this number only 78 puparia were obtained. Most of these were found in beetles of the first few days' collections, and it was consequently surmised that they represented the last of the parasite brood, the peak of attack having taken place several weeks earlier, and that the percentage secured consequently gave no indication of the total mortality effected.

The few puparia secured were set aside for hibernation and for emergence the following season. The first adult (fig. 7) from this material appeared on July 18, and immediate observations were made in the field in the same general locality which furnished the earlier parasitized material to determine whether the laboratory-emergence

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records corresponded to field conditions. On July 20 a single female was captured on a corn tassel in an adjoining field, and from this date onward both sexes were secured in fair numbers. These were determined as *Adapsilia flaviseta* Ald. (*1*).

On the basis of dissections of beetles during this period, it became evident that July 20 was the approximate date of the first oviposition. The great bulk of egg laying occurred during the two weeks following that date, a few females continuing to deposit eggs until August 18 at the latest.

The collection and breeding records, taken in conjunction with field observations, indicate that the correlation between the time of emergence of Adapsilia and that of its hosts is not always so close as might be desired. In 1926 and 1927 this defect was not so evident, as the higher percentages of parasitized beetles were found among the first-emerging Popillia, whereas in 1928 the greater part of the beetles emerged about 10 days prior to extensive oviposition by the parasite. In this year the period of several weeks preceding parasite activity was marked by heavy rains, which may have induced an earlier emergence of the beetles and also served to delay oviposition by the parasite.

NATURAL HABITAT

The very restricted area in which Adapsilia was found to be most abundant in India is at an elevation of 5,000 to 5,100 feet in a very hilly district largely covered with a widely spaced planting of pine trees, and with a fairly dense undergrowth. Small patches in the ravines and on the hillsides were cleared and planted to corn or potatoes. The host beetle breeds in these forested areas where the undergrowth is rather light, and also at the margins of the more dense areas. The adult beetles feed at various blossoms in this undergrowth and also at corn tassels in the near-by cultivated plots.

The Adapsilia adults were to be found in greatest numbers on the undergrowth foliage in ravines largely screened from direct sunlight, though they occasionally venture into the open fields for food.

PERCENTAGE OF PARASITIZATION

While in certain favored locations, such as those just described, the percentage of parasitization may be fairly high, at times approaching 50 percent, the general attack over the whole area infested by *Popillia cupricollis* has been exceedingly light. The collections for 1926 to 1928, inclusive, covering all of the beetle-infested areas within a radius of 10 miles of Shillong, and the number of puparia secured and the percentages of parasitization each year, are shown in table 1.

TABLE 1.—*Percentage of parasitization of Popillia cupricollis by Adapsilia flaviseta in the neigborhood of Shillong, India, 1926–28*

Year	Host beetles collected	Puparia recovered	Degree of parasitization
	Number	*Number*	*Percent*
1926	451,237	6,420	1.42
1927	508,773	8,141	1.60
1928	771,313	4,097	.53

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The decline in the percentage of parasitization in 1928, as compared with that of the preceding 2 years, may be accounted for largely by the constant and thorough collection of all beetles available in the favored localities of the parasite during the preceding years.

SEX OF HOST ATTACKED

A markedly greater proportion of Popillia males than of females is attacked by Adapsilia. This may be due largely to the habits of *P. cupricollis* itself rather than to any actual preference for males by the parasite. Allowing for the sex ratio of the host, approximately twice as many males as females are attacked. Under field conditions the male beetles are active on the food plants during the greater portion of the day, and are on the wing more frequently than the females. The latter feed during the morning hours and then spend a considerable proportion of the afternoon in the soil depositing their eggs. As the parasite attacks the host only while in flight the opportunities for oviposition on the male beetles are considerably greater than those for oviposition on the females.

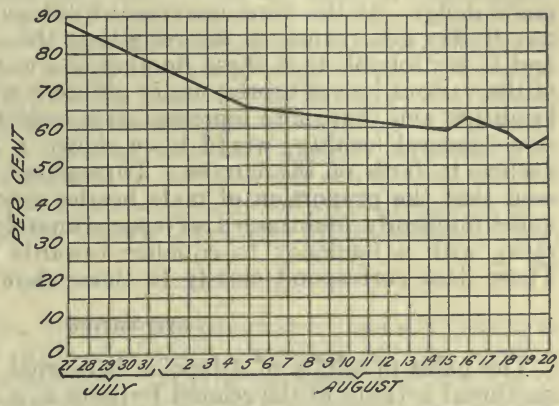

FIGURE 8.—Percentage of males among the hosts of *Adapsilia flaviseta* during the period of attack in 1926.

The percentage of puparia of Adapsilia recovered from male beetles during the season of 1926, as compared with the total of all those parasitized, is shown in figure 8. This is based on an examination for parasitization and host sex of 2,440 parasitized beetles collected on different dates from July 27 to August 20, thus covering practically the entire period of oviposition of Adapsilia in the field. It is seen that in the early portion of the oviposition period, when maximum effectiveness can be attained through the death of the hosts before their extended oviposition has taken place, by far the greater proportion of all progeny are developed in male beetles, whereas the preponderance in this direction is only slight during the latter part of the period. This difference is due to a decline in the proportion of male beetles present and not to a change in habit.

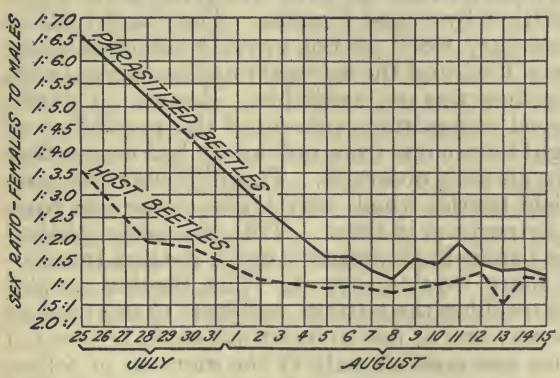

FIGURE 9.—Normal sex ratio of *Popillia* spp. in the field during the time of occurrence of *Adapsilia flaviseta*, as compared with the ratio of those attacked by the parasite, 1927.

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In figure 9 the sex ratios are shown for parasitized beetles for the period during which the parasite was active in the field in 1927, as compared with the normal ratio of the host. The records are based on the examination of the dead beetles in the breeding cages, the collection dates of which were known, and the parasitization figures are based on the puparia found in the bodies of these beetles. The figures for the earlier portion of the period are for a total of approximately 500 beetles for each date of record, these being taken at 2- or 3-day intervals, but during the latter portion of the period the count was made daily. At this time unexpected differences were revealed from day to day not evident in the records in the early part of the period, and it is probable that these fluctuations were due to the collection of the various lots of beetles under different conditions and in various localities, and that more representative collections, all taken from the same general locality, would have shown a gradual and consistent decline in both of the curves. Throughout the entire period it is seen that the proportion of male beetles among those parasitized is quite uniformly maintained at approximately twice the normal sex ratio, with a tendency to equalize towards the end of the period. These data correspond closely to those shown in figure 8 for 1926.

OVIPOSITION

The habit of adults of Adapsilia is diurnal, as contrasted with the nocturnal activity of the related Pyrgota as a parasite of Phyllophaga in the United States (7), and this is essential in view of the diurnal habits of the host beetles. Oviposition was observed in the field in many instances, and apparently takes place only while the host is in flight. The female fly remains quiescent upon foliage in the vicinity of the feeding beetle until the beetle takes flight, whereupon the fly immediately pounces upon the beetle from above. The egg is laid very quickly, and the beetle falls to the ground.

Under such laboratory conditions as were available it was not possible to secure oviposition by caged females. The smaller Riley cages used in general insectary work do not provide sufficient room for flight by the beetles and flies, and the necessary outdoor screen cage of relatively large dimensions was not available. Records of development from field-observed ovipositions presented the possibility of error, as the progeny might have come from previously laid eggs rather than from the ovipositions actually observed. This difficulty was overcome by taking to the field beetles which were known to be free from parasites, and inducing oviposition in them. This was accomplished by catching the Adapsilia female in an ordinary insect net and immediately dropping one or more beetles into it. The beetles usually spread their wings before reaching the bottom, and were then attacked by the parasite. In this way one or two ovipositions could be secured from each female, but this was possible only at the moment of collection, as they refused to oviposit when confined and taken to the laboratory.

The ovipositor of Adapsilia is long, relatively slender, flexible, and armed with a heavily chitinized, sharp tip by means of which the integument of the host is pierced. From a dissection of freshly parasitized hosts it appears that the point of insertion of the ovipositor is in the mid-dorsal region of the abdomen near its juncture with the thorax.

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LIFE CYCLE

There is a single generation of *Adapsilia flaviseta* annually, the principal host being *Popillia cupricollis*, although a few individuals develop in *P. cyanea* and *P. macclellandi* Hope. The winter is passed in the puparium in the body of the host beetle, which is in the soil or under rubbish on the soil surface. Adult emergence begins in the middle of July, and oviposition takes place the latter part of that month and in the first half of August. The egg stage covers approximately 3 days, and the period from oviposition to pupation is from 15 to 18 days. The host beetles of both sexes are killed by the larvae early in their third stage, 3 or 4 days prior to pupation. The parasitized males live slightly longer than do the females, a condition similar to that noted in Japan in the case of Centeter. The body contents are completely consumed, and the puparium is formed with its anterior end closely appressed to the posterior end of the abdomen of the host. In a very few instances two puparia were found to have developed in a single beetle, though these were below normal in size.

SECONDARY PARASITES

In the breeding work in 1926 the puparia in the trays were found to have become infested with chalcidoid parasites of two species, *Spalangia* sp. and a tetrastichid. The larval forms and method of attack were identical with those previously observed on Centeter puparia in Japan, and it appears that these hyperparasites are of general occurrence upon exposed dipterous puparia in the soil or on its surface, rather than being specific or generic in their host relationships.

COLLECTION METHODS

The manner of field collection of Adapsilia material in India was much the same as that of collecting Centeter in northern Japan. The natives living in the areas infested with *Popillia cupricollis* were shown samples of the beetles and offered 5 annas (11 cents) per hundred for all that they could bring in. This very quickly aroused the interest of a large number of people, principally women and children, and in the later years as many as 80,000 beetles a day were brought in, and collections had to be discontinued before the end of the oviposition period of the parasite because of lack of funds. The area covered by the collectors was approximately 10 miles square. In certain small, isolated infestations the collectors were able to secure relatively large numbers in a short time, but the average payment per person was less than 1 rupee (37 cents) per day. The total cost of collection of the 500,000 to 700,000 beetles secured each year was from $570 to $800.

REARING METHODS

Owing to the fact that *P. cupricollis*, the principal host, is a blossom feeder and that the period of larval development of Adapsilia within the living host is relatively long, it was necessary to adopt a different manner of handling from that used with Centeter in Japan. Manifestly it was impracticable to secure enough blossoms to feed a stock of several hundred thousand beetles for several weeks, and consequently tests were made of various foliage plants, as well as of fruits

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and tubers, in an effort to discover some suitable substitute. It was finally found that apples, of which an adequate supply of culls was available at that time, were well suited to this purpose.

Heavy cardboard boxes of approximately one cubic foot capacity were used as containers during the feeding period. A layer of fresh moss was placed in the bottom of each, and upon this enough sliced apples were laid for 500 or 1,000 beetles. The apple pulp decayed very quickly, and the moss served to absorb the excess moisture. The food supply was renewed on alternate days, at which time such of the previous supply as had not been consumed was removed. This feeding was continued for a period of 12 days from the date of collection, and the live beetles then remaining, which were evidently unparasitized, were destroyed. The mortality of unparasitized beetles through unfavorable food and cage conditions was relatively high, though the parasites matured satisfactorily even in beetles which had died during the second larval stage of the parasite, instead of in the third stage as is normally the case.

After the removal of the living beetles, the dead bodies remaining in the boxes were sorted out from the moss with which they were mixed and placed in open trays for drying, as considerable ammonia was being generated through decay, and the Adapsilia still in the larval stage were permitted to pupate. When sufficient time had been allowed for this, the dead bodies were opened and examined for parasite puparia, and to detect and eliminate the large proportion of unparasitized beetles, the unconsumed body contents of which would give rise to decomposition gases in sufficient quantity to affect seriously the vitality of the parasite puparia. In so far as possible the puparia found were permitted to remain in the bodies and were shipped in that condition.

SHIPMENTS

From 1926 to 1928, inclusive, 17,662 puparia of *A. flaviseta* were shipped to the United States. The first year's consignment, of 6,420 puparia, was unfortunately held up in the mails and returned to Shillong several weeks later. It was then repacked and again forwarded by mail, eventually arriving at the Riverton laboratory slightly more than three months from the date of original sending. As a result of this, and also because the puparia were packed too closely and with insufficient means of ventilation, the consignment was a total loss.

The 1927 shipment of 7,601 puparia was packed in small ventilated rectangular tin containers 1 inch deep, with a layer of puparia between two layers of fresh sphagnum moss. A number of such tins were then packed in insect-proof wooden boxes of sufficient size to allow a 3-inch layer of fresh moss to be packed entirely around the series of tins. This consignment was 47 days en route from Shillong to the United States, having been kept at a reported temperature of 40° to 42° F. on the steamer between Calcutta and Boston. Examination upon arrival revealed the puparia to be in good physical condition, with the moss packing still appreciably moist.

The third season's shipment, comprising 3,641 puparia, was packed and forwarded in a similar way, being 50 days in transit at a temperature of 40° to 50° F. en route. Upon examination, 74 percent were estimated to be alive.

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PROBABLE VALUE OF ADAPSILIA IN THE UNITED STATES

A consideration of all factors bearing upon this parasite as noted in its natural habitat in India points to a very low potential value as a parasite of *Popillia japonica* in the United States. Its favored habitat, as previously discussed, is markedly different from that in which this host is found in its most destructive numbers in the United States. Then, too, the greater part of the eggs are laid in male beetles, particularly during the early period of attack, a habit in striking contrast with that of Centeter. From the point of view of reduction in host numbers, the ultimate aim in all parasite introduction work, the value of this attack on the males is nil. Further, the longer period of larval development, as compared with that of the other parasites of adult beetles studied, reduces its value still

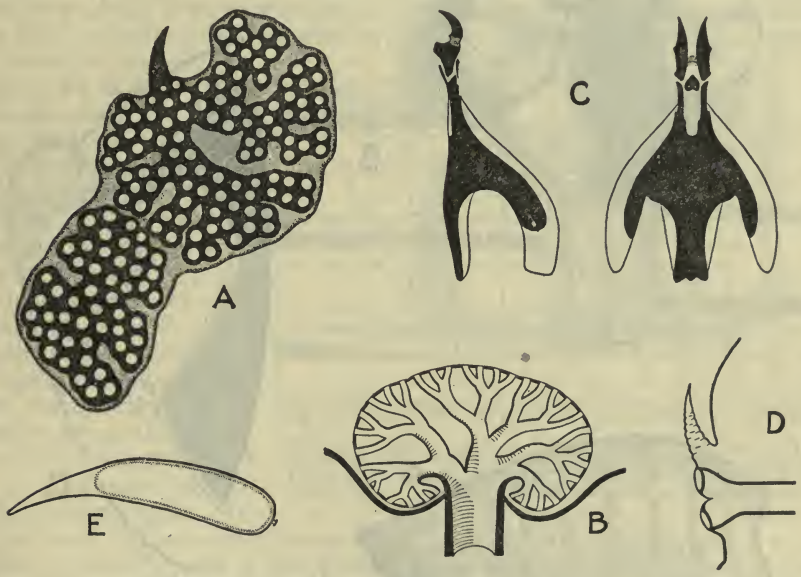

FIGURE 10.—*Adapsilia flaviseta*: A, posterior spiracle of mature larva; B, saggital section of anterior spiracles of third-instar larva; C, mouth hooks of third-instar larva; D, posterior spiracle of second-instar larva; E, the egg, ×30.

more, by permitting oviposition by the host females for a relatively longer period before death ensues. The three principal factors bearing upon parasite effectiveness are therefore, in this case, of minimum value.

CHARACTERS FOR DISTINGUISHING THE IMMATURE STAGES OF ADAPSILIA FLAVISETA

The egg (fig. 10, E): Mature ovarian egg 1.4 mm long and 0.25 mm in maximum width; laid egg 1.3 mm in length. Ventral side pronouncedly concave, dorsal side strongly arched, the anterior half of greatest and uniform width, tapering to a narrow point at the opposite end. Anterior end smoothly rounded, the micropyle large and distinctly button-shaped.

First-instar larva: Body 0.8 mm long, 13-segmented, of greatest width in the mid-abdominal region, with the caudal segments much narrower. Segmentation distinct. Mouth parts much reduced in size and not distinguishable under the higher power of the binocular. Posterior spiracles simple and sessile. Derm with many surface setae or papillae.

Second-instar larva: More robust in form than the first-instar larva, the caudal segments as wide as the greatest body width. Derm with numerous papillae

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at middle of each segment, extending around the body. Mouth hooks similar to those of the third instar, but smaller. Anterior spiracles simple and very small. Posterior spiracles (fig. 10, D) separated by their own width and set in a distinct median posterior depression or cavity. Tracheal trunk branched at the spiracle, forming two openings, one above the other, and surmounted by a dorsally directed hook, the surface of which is transversely wrinkled.

Third-instar larva: Body very robust, in fact weevil-like in form, with the derm markedly glistening. Brownish contents of digestive tract distinctly visible. Mouth hooks (fig. 10, C) as illustrated. Anterior spiracles (fig. 10, B, saggital section) slightly stalked and fan shaped, with the tracheal trunk extensively branched. Posterior spiracles (fig. 10, A) very large, of three main lobes, with a dorsally directed hook at the inner dorsal margin, and placed at the dorsal rim of the large median posterior cavity distinctive of the larvae of this family. Ventral lobe extending into the cavity, and the entire surface of the spiracle

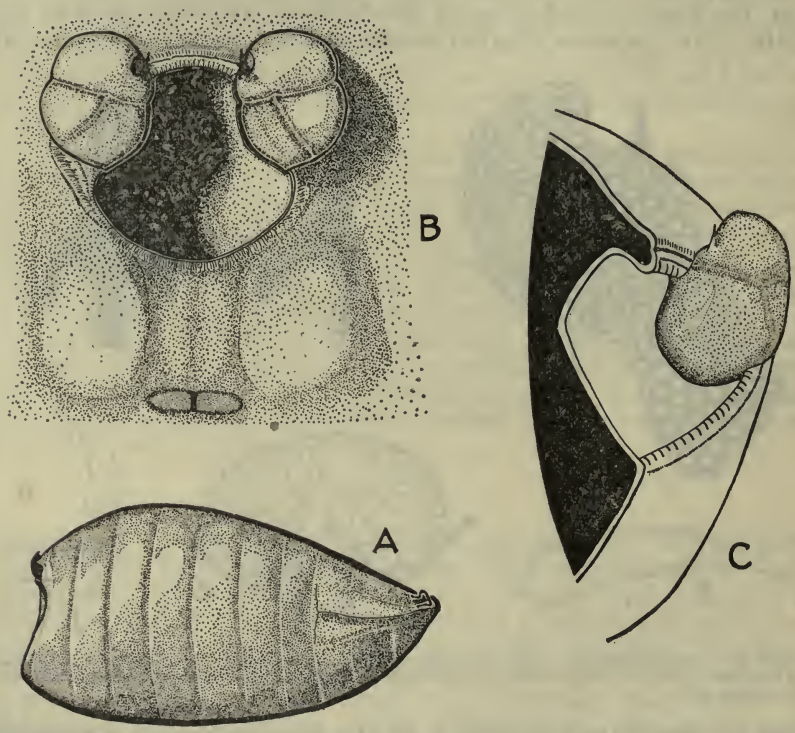

FIGURE 11.—Puparium of *Adapsilia flaviseta*: A, Lateral view, ×6; B, posterior view showing spiracles and central depression, ×25; C, saggital section of posterior portion, ×30. (Parker.)

curved through an arc of approximately 180°. Heavily pigmented, the openings being clear and distinct only in freshly molted individuals.

Puparium (fig. 11, A): Length 8 to 10 mm. Distinctly keel shaped and much the widest in the mid-abdominal region. Dark brown or reddish-brown, with reflections dull. Anterior spiracles large and stalked. Posterior spiracles three lobed and placed at the dorsal margin of the posterior cavity, as shown in figure 11, B and C.

PARASITES OF THE LARVA

DEXIIDAE

DEXIA VENTRALIS ALD.

In view of the complexity of the host relationships of *Dexia ventralis* in Chosen, and the danger incident to shipping it in living grubs other than those of *Popillia japonica* owing to the risk of an escape

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of these species, no shipments were made until 1925. In the meantime the establishment of *Anomala orientalis*, *Autoserica castanea*, and *Serica similis*, three scarabaeid beetles of Asiatic origin, in the eastern part of the United States made more possible the success of the importation by providing at least one of the alternate hosts thought to be necessary in the annual cycle of Dexia.

This species is known to occur in Chosen, Manchuria, and the Malayan region, but extended observations have failed to reveal this or any other species of the genus as parasitic in scarabaeid grubs in the coastal sections of China and in India.

LIFE HISTORY

In the further life-history studies which have been made of this species during 1924 and 1928 additional facts have been revealed relative to the host relationships of the species, and these were found to vary considerably from year to year owing to the changing host population in the soil. In figure 12 is shown the developmental cycle for 1924, starting with the overwintering larvae in the various host grubs. In that winter the young larvae were largely contained in grubs of *Miridiba koreana* N. and K., *Popillia castanoptera*, and *Phyllopertha* spp., and on examination in the early spring they were found to be in a healthy and active condition in all of these hosts. As time went on, however, it was found that those in Phyllopertha were dying gradually, and in the end all disappeared without reaching maturity. Those in Miridiba developed normally and pupated during May, the first brood of adults appearing in the field late in May and during the first half of June. The progeny of these flies parasitized the mature grubs of *Popillia castanoptera* then available, and a second brood of adults resulted late in July and during the first half of August. The larvae produced by these females in turn found only Serica grubs in suitable condition for the production of another generation, and the third and final brood of adults developing from them appeared during September and the first half of October. The progeny of these females were then distributed among the various host-grub species, suitable and otherwise, occurring in the soil at that time. It is thus seen that in the three-generation phase of *Dexia ventralis* each generation develops in a different scarabaeid subfamily, namely, Melolonthinae, Rutelinae, and Sericinae, respectively, the overwintering host being listed first.

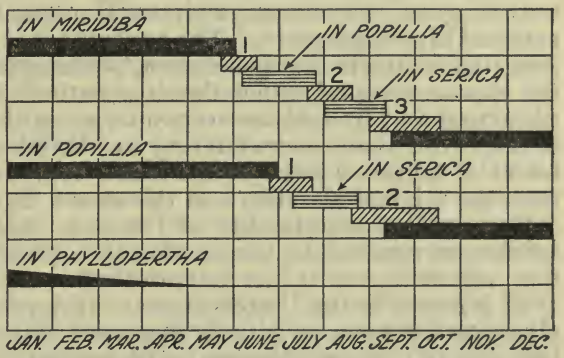

FIGURE 12.—Seasonal cycle of *Dexia ventralis* in different hosts in Chosen in 1924. The numbers refer to the successive broods of adults of the parasite, the heavy black bars are the overwintering grubs, and the horizontal-ruled blocks represent the summer grubs.

The cycle of three generations, however, represents only a portion of the Dexia population. Those individuals overwintering in Popillia are delayed in development and reach maturity and pupate

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from the middle to the end of June, approximately 1 month later than those in Miridiba, as the host attains the proper stage at a later date, and consequently the adults appear in the field at the end of June and during the first 3 weeks in July. This is too late for the production of the succeeding generation on the same host, as practically all have either pupated or already emerged. The enforced alternative is therefore to attack directly the Serica grubs then available, and this attack consequently takes place somewhat earlier than that of the second generation from Miridiba. The adults of the second brood from Popillia emerge somewhat earlier than those of the third from Miridiba but persist for a longer period, the activities of both being terminated by the advent of cold weather in the middle of October. Thus, with Popillia as the winter host it is found that only two generations a year are produced instead of three.

The complexity in the host relationships as just described and the life cycle of the parasite result in the presence of adult flies in varying numbers in the field throughout the season. It is possible, however, to distinguish the successive broods of adults by the numerical peaks attained after emergence. The apparent first brood, as distinguished from the complete first generation, is numerically the greatest, while the apparent second, which develops entirely from Popillia, is in part the actual first from those overwintering in that host and in part the second from those overwintering in Miridiba. The apparent third brood of adults is from Serica alone, representing the actual third from the original Miridiba and the second from Popillia.

This evident adaptability of Dexia to the conditions of the host species, as opposed to the previously considered obligatory alternation, enhances greatly the potential value of the species as a parasite of *P. japonica* in the United States. It appears improbable that the alternate hosts can be entirely dispensed with, and the presence of at least one of these would seem to be essential to the attainment of an effective status against *P. japonica*. In general it may be said that the advent of an obligatory alternate host into the economy of a parasite species results disadvantageously unless the former is at least numerically equal to the host to be controlled. The factor of numerical abundance of the host has a particular bearing in this instance as determining directly the percentage of parasite planidia which ultimately find hosts and develop to maturity.

An examination of the habits of the first-stage larva reveals that it exercises no apparent discrimination in the choice of host grubs, and that the factor influencing the relative degree of attack upon the various grub species is the physical character of the grubs themselves. In connection with the hibernation experiment in 1928, records were made of the percentage of penetration effected upon the various host species in different stages. Included in this series were grubs of *Popillia castanoptera*, *P. atrocoerulea* Bates, *Miridiba koreana*, *Phyllophaga* sp., *Phyllopertha* spp., *Anomala* spp., and *Serica* spp. Two methods of securing parasitization were used, those of direct application of planidia to the grubs by brush and the caging of gravid females over soil containing grubs.

Under identical conditions a marked variation was noted in the percentage of grubs containing planidia after a certain period in the cages or the inoculation blocks. In the inoculation cells, with from 5 to 10 planidia placed directly upon each grub, which was then cov-

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ered with soil and confined therein for 2 days, the general rate of parasitization was good with both species of Popillia, with *Miridiba koreana*, mature Serica, and second and early third stage Phyllophaga, medium in the smaller species of Anomala and early second-stage Serica, and very poor in the large Anomala and in third-stage Phyllopertha. The extremes in results were represented by an 18 percent parasitization of the larger Anomala as contrasted with an 85 percent parasitization in the second and early third stages of Phyllophaga. It is very evident that if this result is indicative of preference or greater physical suitability, then the instincts of the larva are greatly at fault in choosing above all others a host species in which development to maturity cannot possibly occur. An examination of this series of grubs, however, indicated that the relative thickness and toughness of the integument of the host grubs is the determining factor. The larger Anomala has an exceedingly heavily chitinized integument, its surface covered with numerous setae, as compared with the very thin and bare integument of the second and early third stage larvae of Phyllophaga. The other species listed may be considered as intermediate between these two in this respect. The lower percentage of parasitization of early second-stage Serica, as compared with the mature grubs of the same species, is attributed, not to the above-mentioned factor, but to the very small size and great activity of the young grubs themselves in relation to the space and volume of soil in the inoculation cells. Their activity results in the planidia being quickly brushed off the body, and the relatively far greater volume of soil present then renders the finding of the grub again correspondingly more difficult. Also there is a lack of intersegmental sutures on the body to provide the more ready points of entry.

Two principal mortality factors are involved in the life of the early larval stages in the host, the first being the defensive reactions set up by the host body, largely represented in this instance by Phyllophaga, and second, the molting of the host, resulting in injury and death to the parasite. In unsuitable hosts death is brought about by phagocytic action and occurs largely in the first larval stage, and occasionally in the second. The respiratory funnel attachment to the host derm is broken after death, and the body of the parasite becomes a darkened, encysted mass imbedded in the host tissues near the original point of entry. In the molting of the normal hosts some of the larvae are killed, but their death does not inevitably follow, the general result being merely the loss of the respiratory funnel with the host exuvium, the larva remaining with its posterior end fixed in the aperture in the integument of the succeeding stage, and eventually forming another funnel.

As in *Prosena sibirita*, it has been determined that although the normal condition is for the larva to attain maturity and pupate only in grubs which themselves are undergoing histolytic action preparatory to pupation, yet this is not an essential condition, and the changes and development to maturity can be accomplished in immature host grubs.

REARING AND SHIPPING METHODS

The breeding work in preparation for shipment to the United States was started in 1925. Grubs of *Popillia japonica* only were used, and these were shipped south from Hokkaido to Fukuoka in Kyushu, to which place the Dexia females from Chosen were also forwarded.

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This was made necessary by the fact that *P. japonica* does not occur in Chosen; consequently the risk of its accidental introduction into that country could not be taken. The supply of *P. japonica* grubs of the proper stage of development was very limited, that year (1925) being the one in the biennial cycle of the beetle in which all grubs pupated and emerged. By the time a sufficient supply of gravid females of Dexia was available, late in June, a very high percentage of the grubs collected had developed beyond the stage of usefulness for parasitization.

The following year (1926) the fall brood of adult flies was used for the artificial parasitization of 2,500 native grubs, largely *P. castanoptera*, and these were placed in hibernation quarters under sod during the winter. They were dug up at the end of the following April and yielded 115 puparia, 130 mature larvae, and 699 larvae still within the living host grubs.

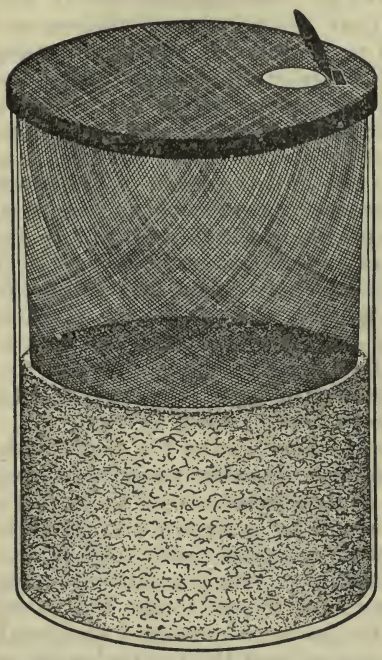

FIGURE 13.—Breeding jar used in the parasitization work with *Dexia ventralis*.

In 1927 it was arranged to utilize the native grubs in Chosen as hosts during shipment, special precautions being taken in packing and in handling on arrival to eliminate any possibility of escape. Breeding work was carried on with females caged over soil containing grubs, and by placing planidia dissected from gravid females on the grubs, the method previously perfected for use with Prosena in northern Japan. From the first brood of flies 1,200 females were dissected and the planidia obtained placed upon 8,824 grubs, 4,463 of which were successfully parasitized.

With the second brood of flies the breeding-jar method was adopted as being less laborious and less wasteful of the parasite supply, which was not so great as in the preceding generation. One-quart glass jars were fitted with copper screen cages (fig. 13), and 20 to 30 grubs were placed in soil in the bottom of the jar and 5 or 6 flies in the cage above. The grubs were examined daily, and those showing parasite penetration, as evidenced by the respiratory funnel attached to the derm, were removed. By this method 6,060 grubs were parasitized by 492 Dexia females. It was found in this and the later work that a general average of 1 to 1.5 successfully parasitized grubs a day could be obtained from each fly.

Experiments were conducted in the shipping of field-collected females from Chosen to Yokohama for use in breeding work there. In a consignment of 200, which was 2 days in transit, only 3 were found dead on arrival. The shipping containers were the same as those used in forwarding scoliid adults to the United States (fig. 16),

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the only change being the substitution of soil for moss in the bottom of the tins; thus any planidia deposited en route would be alive and could be used on arrival. The maximum length of life of the flies shipped was 19 days during relatively cool weather.

The life of the planidia in the soil was found to be shorter than had been supposed. Relatively few grubs were parasitized after the fourth day, though a few parasitizations were obtained up to the seventh day.

SHIPMENTS

The first consignment of parasitized grubs was forwarded in 1925, consisting of 850 of *P. japonica*; this was followed by 8,624 of various suitable hosts from Chosen in 1926, and 864 of the same and of already-formed Dexia puparia, with 10,986 grubs of *P. castanoptera* alone in 1927. The duration of the life cycle of the parasite is such that the majority of the flies are in the pupal stage and ready for emergence on arrival at the laboratory in the United States.

Prosena sibirita (Fab.)

FIELD OBSERVATIONS

The dexiid *Prosena sibirita* is an important parasite of the grubs of *Popillia japonica* in northern Japan. Elsewhere, however, even though adults may be observed in abundance, only an occasional individual of the various species of Popillia can be found containing its larva.

This species is generally distributed throughout the entire Asiatic and Malayan regions, and adults were commonly seen during the course of the investigations in Chosen, China, and India. In northern Japan it is primarily a parasite of *P. japonica*, normally effecting a field parasitization of from 10 to 15 percent, and it also occurs to a lesser extent on Anomala and Serica. In Chosen an occasional larva was found in Popillia and in various sericine grubs, whereas in China no record of the species as a parasite of any of the Popillia occurring there was made during the 4 years of investigation in that country. In India it was noted that a very few field-collected grubs of *P. cupricollis* contained Prosena larvae, but by far the greater number of the parasites were found in the various species of Serica. In Java *Prosena sibirita* is recorded as a parasite of Adoretus.

As a result of the earlier studies upon the habits of *Prosena sibirita* in northern Japan it had been concluded that the final stages of development of the larva could take place only in host grubs which themselves were undergoing histolytic action preparatory to pupation; and this conclusion was borne out by the time of appearance of the adult flies, which in that section appeared in the field about 2 weeks after the time of emergence of the host beetles, and persisted until September. It has since been found, however, that this condition is not essential, even though normal, as some larvae complete feeding and pupate from smaller grubs which would otherwise carry over until the following season before attaining maturity.

At Shillong, India, the earliest observation of adult flies in the field was April 9, when several females were seen feeding at the blossoms of apple, and they were present continuously from that date until the end of September. Those which were reared from *Popillia*

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cupricollis emerged at the end of June, and those from Serica in July. The parasitization of the latter host at this time was found to approximate 25 percent.

During the earlier investigations on this species at Koiwai, Japan, it was noted that there were three forms of adults of Prosena in the field, differing appreciably in size, coloration of the abdomen, and somewhat in the time of appearance. It was assumed at that time that these represented distinct species, and their hosts had been determined as *Serica* sp., *Popillia japonica*, and *Anomala* sp., respectively, in the order of size of the adult flies. Aldrich, however, has made repeated examinations of all characters of these forms, including the genitalia, and declares them to be specifically the same. The intermediate and smaller forms only were noted at Sapporo, whereas in Chosen during the late summer only the large form is to be seen. The variation in the size of the three forms and their differing times of emergence could result from corresponding differences in the host species, but the distinguishing coloration of the abdomen of these forms can hardly be explained on the same basis.

BREEDING AND SHIPPING METHODS

During the first two seasons' investigations upon *Prosena sibirita* (1921 and 1922) a method was devised whereby host grubs in large numbers could be artificially parasitized with the first-stage larvae taken from the ovisacs of the gravid females, and these grubs then shipped immediately. In the following 5 years this method was abandoned in favor of the forwarding of field-collected grubs, which showed a general parasitization each year approximating 10 to 15 percent. Collections were made in Hokkaido in the early spring and forwarded in late May, so as to arrive at the laboratory in the United States just before emergence. This method proved satisfactory, as the emergence of adult parasites was estimated at 70 percent of the original parasite content at the time of collection. The cost involved, however, was considerable as, aside from the cost of collection and crating in Japan, each consignment of grubs (25,000 to 50,000 packed in soil) involved a heavy expenditure for transportation.

Because of the cost handicap, as explained above, the artificial parasitization of grubs in the late summer and fall was again taken up in 1927. Instead of being shipped immediately, however, these parasitized grubs were placed in a prepared soil plot, well drained and covered with sod, where they were left for the winter. To prevent the grubs wandering away, the plot was inclosed to a depth of 18 inches in fine-mesh screen, the surface being also covered with the same material to prevent loss by rodents and birds.

When the parasitized grubs were overwintered as above, the proportion available for shipment the following spring was approximately 60 percent. Owing to their high parasite content, the shipping cost was thus reduced to about 20 percent of the previous cost of shipping an equal number of parasites.

The shipping containers used in the earlier consignments provided about 3 cubic inches of soil and grass roots for each grub, the cases being separated into compartments by cross-section sets of wood, zinc, or tin. The shipments of 1927–28 were contained in tin-lined boxes 1 foot square and 6 inches deep, inside, each containing five cross-section sets separated by tin plates and providing a compart-

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ment of approximately 1 cubic inch for each of 500 grubs. It was found unnecessary to provide grass roots for feeding in transit, and the soil used was first thoroughly screened and then fumigated with carbon disulphide to eliminate any other soil-inhabiting insects which might be present.

SHIPMENTS

From 1921 to 1928 13,600 artificially parasitized grubs and 159,000 collected in the field, the latter having a general parasite content of about 10 percent, were shipped from northern Japan to the United States. In addition, 40,596 grubs were artificially parasitized in the late summer of 1928 and placed in winter quarters, to be forwarded the following season.

SCOLIIDAE

During the course of the investigations on parasites of Popillia in Japan, Chosen, China, and India during the period from 1920 to 1928, inclusive, a large number of scoliid species, principally Tiphia, were found to attack the grubs of this genus. The habits of these species, as well as those of many on other scarabaeid genera, have been intensively studied.

In general the conclusion has been reached that, under conditions such as exist in agricultural sections in Asia and in the United States, Tiphia is unable to achieve the role of an important controlling factor in the economy of its hosts. In the case of a great many species of Tiphia localized infestations have been observed in which relatively high percentages of host grubs were attacked, but none of the species has been seen to occur in numbers sufficiently great throughout the entire host habitat to exert any appreciable check upon it. There is little basis for hope of greater effectiveness by any one species under the conditions existing in the sections of the United States now inhabited by Popillia, though there may be some possibility that the aggregate effect of a series of species might contribute appreciably to its ultimate control.

One of the main limiting factors bearing on Tiphia is that of the food supply of the adults, which is derived from three general sources—the honeydew secreted by aphids and other bugs,the blossoms of various plants, particularly Unbelliferae and Polygonaceae, and the nectar glands associated with the foliage of certain plants, such as Polygonum and sweetpotato. The spring species in general feed upon insect secretions, the summer species on these and also at various blossoms, and those occurring in the fall at blossoms and nectar glands. It is thus evident that the maintenance of a large Tiphia population throughout the season is entirely dependent on the presence of aphid-infested plants and of the various weeds bearing suitable blossoms and nectar glands. This condition is in opposition to the best agricultural practice, which involves the elimination of weeds and the control of such bugs as infest cultivated crops. These latter may occur in limited numbers, but again they may be entirely absent over large areas heavily infested by the beetle.

In only a single instance, that of *Tiphia matura* in India, has a scoliid been known to have its normal source of food supply at an appreciable distance from the host infestation, and to continue this condition from year to year. The more usual development in the event of failure of the local food supply is mass migration to another

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locality for oviposition as well as feeding. Even with the food supply available in the immediate vicinity, the fluctuation in numbers in a given locality from year to year is very great.

Another factor affecting Tiphia adversely in cultivated sections is the destruction of the cocoons through soil cultivation. Were the mortality of host grubs proportionately as great, the numerical reduction would have no serious result, but such is not the case. Very few Scoliidae are able to reach maturity and emerge where the soil cell in which the cocoon has been formed is broken. This factor is of little consequence in relation to Scolia or Campsomeris, as with these genera the host grub is usually buried and the cocoon is formed considerably below the customary depth of cultivation.

The host relationships of the various species of Scoliidae parasitic upon scarabaeid grubs have been found to be generally within generic rather than specific limits. In any given locality, however, each species confines itself very largely, and at times entirely, to a single host species. This apparent specificity may be obligatory, as in the case of *Tiphia popilliavora* in Japan, where it is due to the presence of only the one species of the host genus in the locality, though it may extend to different hosts in other regions.

The life cycles of the species of Tiphia occurring in the Temperate Zone are similar, there being usually a single generation each year, and the winter being passed within the cocoon in the soil. Comparatively few of the species that occur in the warmer localities produce 2 generations annually, though as many as 5 or 6 may develop under optimum conditions in the Tropics. The dormant stage in temperate regions may be either the mature larva, the pupa, or the adult in the cocoon, the latter being the case with those species that emerge early in the spring, and which presumably would produce a second generation annually under slightly more favorable conditions.

In all of the species of Scoliidae studied, comprising the genera Scolia, Campsomeris, and Tiphia, the egg position on the host grub has been found to be a specific constant. In figure 14 this position is illustrated for all of the species discussed in this bulletin.

Campsomeris annulata Fab.

GENERAL OBSERVATIONS

While there was considerable doubt regarding the ability of *Campsomeris annulata* to adapt itself successfully to *Popillia japonica* as a host in the United States, yet the comparative facility with which it could be secured in numbers permitted an extensive experimental program in 1925 and 1926. The native hosts of this widely distributed scoliid are usually the grubs of the larger ruteline species, particularly species of Anomala and at times *Phyllophaga diomphalia* Bates, and its range in host groups is considerably greater than is found in Tiphia. Under American conditions it was hoped that at least one of its multiple generations would develop upon *P. japonica*. However, the large-scale importations and colonizations have apparently failed of establishment.

The life cycle under experimental conditions varies considerably with changing temperatures. In Chosen in midsummer the durations of the stages were 2½ days for incubation of the egg, 5 days in the larval-feeding stage prior to the formation of the cocoon, and 21

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days in the cocoon. These figures may be taken to represent the minimum developmental cycle of the species.

In Japan and Chosen there are apparently three generations a year, the winter being passed largely in the pupal stage in the cocoon. In the coastal sections of China an additional generation is produced. In Chosen the first adults were seen in the field April 30 and persisted throughout the season, the broods being largely intermixed, and the last of these most abundant during October. In China the first individuals were taken on March 8; the first brood was at its peak during the middle of May, the second in the latter part of July, the third at the end of August and in early September, and the last at the end of September and in the first half of October. There are some indications that a portion of the last brood of adults hibernates during the winter in that stage, but this point has not as yet been demonstrated conclusively.

The adults feed exclusively at various blossoms, particularly those of thistle, wild carrot, white clover, *Vitex negundo*, and goldenrod, and never on the liquid excretions of insects. The females are seen

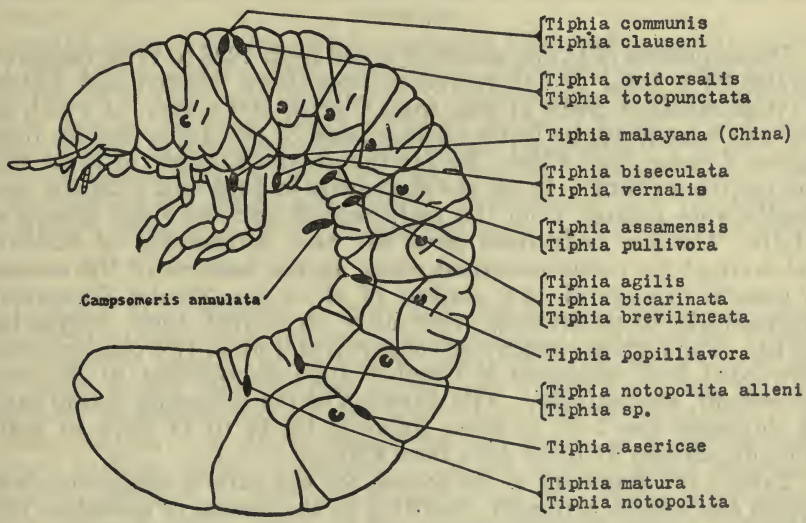

FIGURE 14.—The position of the eggs of various Scoliidae on the host grub.

largely during the morning hours and until 1 p.m., the males predominating during the afternoon.

REARING METHODS

Owing to the permanent paralysis of its various host grubs at the time of oviposition by Campsomeris, the methods of rearing and shipping the immature stages differed considerably from those employed with Tiphia. In Chosen 1,000 ovipositions were obtained in 1925, though with some difficulty, as the females did not oviposit readily in captivity. During the egg stage there was considerable loss through the death of host grubs and from the parasite egg being rubbed off by relatively slight movements of imperfectly paralyzed hosts. The 1,000 ovipositions finally resulted in 219 cocoons being formed. Similar methods employed in China gave much better results.

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In the following season's work, both in Chosen and China, individual clay cells were used for shipping purposes, the paralyzed grubs being placed therein as soon as the eggs had hatched. These cells were first soaked in water, the grubs were inserted with a small quantity of moist moss, and the cells were corked. The cells were then packed in wooden containers, with a considerable quantity of moist moss, and immediately forwarded.

The proportion of cocoons formed in the cells en route ranged from 10 to 53 percent, the most successful shipments being two small lots from China in 1926 yielding 46 and 53 percent, respectively. The general average, however, was low, and in view of the success attained in shipping adult females the more laborious rearing method was abandoned.

It is interesting to note that a variable proportion of the paralyzed grubs forwarded upon which the parasite larva did not develop were still alive on arrival in the United States. The maximum percentage of these in any one shipment was 75, and these were examined approximately 30 days after parasitization.

SHIPMENTS

The shipments of *C. annulata* forwarded from 1923 to 1926, inclusive, comprised a total of 348 reared cocoons from Chosen and China, 6,416 parasitized grubs in cells from Chosen and China, of which all but 219 were from the latter country, and 31,060 adult females from Japan, Chosen, and China, by far the greater number of these also coming from China. In all the shipments in 1925 and 1926 the best results were secured from the early second and the third broods of adults. October collections gave the best percentages of survival but were of no value on arrival owing to the lateness of the season. A general average of 13.6 percent of all of the females forwarded, representing all generations, were alive on arrival, these numbering 4,219. The highest percentages of survival were in two consignments forwarded from Shanghai in October 1925, amounting to 78.3 and 82 percent, respectively. The duration of the collecting period prior to shipment was 7 to 15 days, followed by 14 to 17 days en route from Japan and 21 to 27 days from China.

Table 2 is a summary of the records for the various shipments from Japan and China, arranged according to the month of collection and shipment, and giving the totals and percentages of survival.

TABLE 2.—*Summary of shipments of adults of Campsomeris annulata, 1925–26*

Month	Shipped from—	Parasites shipped	Parasites surviving	
		Number	*Number*	*Percent*
May	China	5,155	688	13.3
June	do	7,500	838	11.2
July	do	7,223	249	3.4
Do	Japan	1,302	244	18.7
August	China	7,571	921	12.2
September	do	1,032	257	24.9
October	do	1,277	1,022	80.0
Total		31,060	4,219	13.6

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Tiphia popilliavora Roh.

GENERAL OBSERVATIONS

In Japan, *Tiphia popilliavora* was found in abundance at Koiwai, Iwateken, in 1920, and breeding work was conducted in that locality for several years. With the exception of those from this locality, and the record of three individuals taken at Yokohama in September and October, 1921, not a single specimen of the species has been collected in the islands of Japan during the eight years the investigations have been in progress. This very localized distribution is surprising in view of the wide distribution, under greatly differing climatic conditions, of the host. The present known range of distribution of the species, outside of Japan, extends to Suigen, Chosen, and Penniu and Hangchow, China, and in these countries also the same markedly localized distribution occurs.

In the previous publication (*6*) a fairly extended account of the life history and habits of *T. popilliavora*, as determined at Koiwai, was given, and the additional data here presented deal with the species on other hosts, and under different climatic conditions, in China and Chosen.

On the basis of the taxonomic studies of Allen and Jaynes (*3, p. 53*) on the Asiatic Tiphia, based largely on the collections made during the course of this parasite project, *T. popilliavora* is represented by three strains, or races, which occur in Japan, Chosen, and China, respectively, and present only very slight morphological differences. The Japanese race is parasitic on *Popillia japonica* alone, the Chosenese on *P. atrocoerulea* and *P. castanoptera*, and the Chinese race on *P. formosana* Arrow, *P. chinensis*, and others of the same genus.

LIFE HISTORY AND REARING RECORDS

In time of emergence in the field the northern-Japanese form ordinarily appears first, occurring from August 15 or 20 to the middle of September, whereas in Chosen the duration of the period is of about the same length, but the first appearance varies from year to year between the middle of August and the middle of September. In China (Penniu) the adults appear the latter part of September and persist until the middle of October. Thus in these localities the period of adult presence in the field is during the few weeks immediately preceding the cooler period of fall, which naturally begins earlier in northern Japan than in the more southern latitudes.

The egg is placed ventrally between the fifth and sixth abdominal segments, and this position is constant for the Japanese and Chinese forms, but at Suigen, Chosen, as a parasite of *Popillia atrocoerulea*, the more general position is between the sixth and seventh segments.

A comparison of the rearing records of the respective races reveals several points of interest. Upon *Popillia japonica* at Koiwai, Japan, the maximum number of eggs obtained from a single female was 47, the general average being less than 15 for the several hundred in the breeding series. In contrast to this, a female collected at Penniu, China, deposited the surprising total of 115 eggs on grubs of *Popillia* spp., and a series of 46 females averaged 54.9 eggs each. The averages for the entire series in China during the three years are shown in Table 3.

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TABLE 3.—*Rearing records of Tiphia popilliavora obtained at Penniu, China, 1925–27*

Year	Females in tests	Eggs laid	Average per female	Cocoons formed	Ratio of cocoons to ovipositions
	Number	*Number*	*Number*	*Number*	*Percent*
1925	482	11,307	23.5	7,794	68.9
1926	460	13,071	28.4	7,738	59.2
1927	513	15,799	30.8	9,306	58.9

It will be seen that the average number of eggs per female ranged from 23.5 to 30.8, as contrasted with less than 15 for the Japanese race. In the percentage of cocoons formed from the total of ovipositions the records are 41 percent for Japan in 1922, 21.4 and 25 percent for two series in Chosen in 1925, and, contrasted therewith, 58.9 to 68.9 percent of the much greater oviposition totals in China, under similar rearing conditions.

It is evident that the Chinese race of *Tiphia popilliavora* has nearly double the reproductive capacity of those in Japan and Chosen, and considerably in excess of the generally accepted average for the genus. In the percentage of ovipositions which yielded cocoons is found also an indication of greater adaptability in overcoming adverse environmental conditions.

In view of the apparent superiority of the Chinese race in fecundity and growth it might be expected that the field parasitization of the host species would be correspondingly greater. This, however, does not appear to be the case. The Japanese race at Koiwai, though of limited range, was found to effect a parasitization of approximately 20 percent of the host-grub population each year, whereas in Chosen, in 1925, the parasitization in a relatively small number of grubs brought in was 10 percent, this representing the maximum noted for that section during the course of the investigations. At Penniu, China, the field parasitization was found to be only 3.5 percent in 1926, as determined by an examination of over 15,000 grubs brought in during the course of the breeding work. Although the foregoing figures do not fully represent the field effectiveness of the species, owing to the fact that a portion of the collections were made early in the oviposition period, yet the conditions were very nearly similar in the various fields, and the percentages given are felt to represent closely the relative extent of parasitization achieved.

As an illustration of the effect of temperature on the development of the early stages of Tiphia, the data at hand regarding *T. popilliavora* in its various localities may be cited. At Koiwai, Japan, in late August and early September the egg stage covered 8 days and the larval stage, to the formation of the cocoon, 18 to 30 days, whereas at Yokohama these were 4 and 14 days, respectively, with a maximum temperature range during the period of development of 80° to 97° F. In Chosen in early September this was further reduced to 3, and 11 to 12 days, respectively, under high-temperature conditions. At Penniu, China, the combined egg and larval stages covered 22 to 24 days at normal temperatures, while in a heated laboratory at from 60° to 70° only 15 days was required.

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SHIPMENTS

Very extensive shipments of reared cocoons of *T. popilliavora* were made from Japan in 1920 to 1923, and from China in 1925 to 1927, inclusive, and a very small number also from Chosen. The shipments of recent years have been utilized to strengthen the already-established colonies in New Jersey and to extend the distribution to the outlying areas of the beetle infestation. In 1925 and 1926 consignments of adult females were also forwarded, but the percentage alive on arrival was exceedingly low, as compared with that secured with those species emerging in the spring and early summer.

During the period from 1920 to 1928, inclusive, 2,249 adult females were shipped from Japan, and 30,134 cocoons from Japan, Chosen, and China. Approximately 25,000 of the latter were from southern China.

TIPHIA VERNALIS ROH.

GENERAL OBSERVATIONS

The life history and general habits of *Tiphia vernalis* have been fully treated in the previous publication (*6*), but additional data are now available regarding its distribution and host relationships.

Through the determination of miscellaneous material collected in the field the species is known to occur in small numbers at Yokohama and Asakawa, Japan, and at Kuling, Zehsah, Hangchow, and Zakow, China, in addition to the original locality of discovery at Suigen, Chosen. The range of distribution is thus comparable to that of *Tiphia popilliavora*, as is also the marked localization of the infestations.

The original finding of this species in Chosen indicated its normal host in that country to be *Popillia castanoptera*. The few individuals collected in Japan in 1920 and 1921, now determined as *Tiphia vernalis*, were at that time tested upon *P. japonica* and found to parasitize it readily, but the very small numbers available prevented any further work being done on them. In view of the fact that *P. japonica* is the only representative of the genus occurring in the localities in which the Tiphia specimens were collected, it may be assumed with some certainty that this is the normal host in Japan. In China the species known to be attacked are *P. chinensis* and several others of the genus. Under field conditions in 1923, 1924, and 1925 in Chosen *T. vernalis* was found to parasitize approximately 10, 6, and 10 percent, respectively, of the grubs of the preferred host, *P. castanoptera*.

LIFE-HISTORY NOTES

In Chosen the duration of the egg and larval stages, to the formation of the cocoon, was found to be 7 to 13 days and 20 to 25 days, respectively, dependent upon temperatures, which vary greatly from the time the adults first appear in early May until the completion of development of the larvae in early July. From eggs secured at Zakow, China, in late April and early May, 1926, it was determined that the two stages covered 9 and 10 days, respectively, in that section—a very appreciable difference from that given for Chosen and one which may be attributed to very high temperatures prevailing during the period of development of the larvae.

The daily oviposition rate of *T. vernalis* in the breeding cages is relatively low, averaging slightly less than 0.5 egg per day per female

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over a period of about 1 month, as compared with the 1.5 eggs per day of *T. popilliavora* during a period of approximately 3 weeks. In the production of cocoons the yearly average ranged from 40.6 percent of the ovipositions in Chosen in 1923 to 56.6 percent for a small lot in China in 1926.

SHIPMENTS

During the years 1924 to 1927, inclusive, 21,455 cocoons of *Tiphia vernalis* were reared and shipped from Chosen and 234 from China, and from 1926 to 1928 the shipments of adult females from Chosen totaled 21,442. The much greater success resulting from the forwarding of adults rather than cocoons has led to the abandonment altogether of breeding work on this species.

In the shipment of adults of this species it was found that the highest percentages of survival were secured in those consignments which had been collected soon after the emergence of the wasps, when they had mated and become fully fed on their normal food, yet had not accomplished any extensive oviposition. The survival figures for the various shipments are given in table 4.

TABLE 4.—*Survival of adults of Tiphia vernalis during shipment from Chosen to the United States, 1926–28*

Year	Shipment	Adults shipped	Adults surviving shipment	
		Number	*Number*	*Percent*
1926	First shipment	990	99	10.0
	Second shipment	1,535	43	2.8
	Third shipment	1,800	312	17.3
1927	First shipment	3,584	2,841	79.3
	Second shipment	6,284	2,370	37.7
1928	First shipment	3,298	1,396	42.3
	Second shipment	3,951	159	4.0
Total or average		21,442	7,220	33.7

TIPHIA MATURA A. AND J.

GENERAL OBSERVATIONS

The first of the natural enemies of Popillia to be encountered in India was *Tiphia matura*, which was found in varying numbers in the Khasi Hills of Assam in the district surrounding Shillong, at an elevation of 4,800 to 6,400 feet. Its normal hosts are the several spring and early summer species of Popillia, principally *P. cupricollis*.

During May and June, 1925, grubs were frequently brought in which bore Tiphia eggs ventrally between the penultimate and last segments of the abdomen, but very few females of species with the habit of placing the egg in this position could be found; in fact, only seven were collected during this first season.

As investigations in 1926 and 1927 revealed new collection areas, an ample supply of females was available for the breeding work. The areas where these were found in numbers were widely separated and apparently determined primarily by the food supply, this consisting of the fluids voided by aphids and other bugs. On the other hand, the more extensive breeding areas were in sparsely planted pine forests in which the branches of the trees up to about 20 feet had been removed,

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and the undergrowth was light, owing to its being cut each year. The soil in these localities is very gravelly and well drained. A maximum field parasitization of about 20 percent was observed, based on a count of grubs bearing eggs or larvae, and of fresh cocoons in the soil.

The wide separation of the breeding and feeding areas of this species is in contrast to the condition existing with respect to the other species of the genus which have been studied, as it had previously been concluded that the flight capabilities of Tiphia in general were relatively limited. The number of parasitized grubs in the soil in the areas where the host grubs occurred in abundance was out of all proportion to the number of Tiphia females which could be found there. These main breeding grounds of the beetle were situated at an elevation of from 5,000 to 5,200 feet in very hilly country, and were bordered on one side by a range of heavily forested hills rising to an elevation of 6,400 feet. It was only after extensive scouting that the feeding grounds of the parasite were found, and these were finally located at the crest of the range of hills several miles away, and at the border between the forested area and the largely uncultivated plateau district beyond. At the margin of the forest was a considerable growth of shrubs of various kinds heavily infested with aphids. Here the Tiphia congregated from 8 to 11 o'clock each morning in large numbers, and it was possible to collect several hundred on a single small bush.

The uncultivated plateau area previously mentioned appeared to be an ideal locality for the development of Popillia itself, and it was at first thought that the Tiphia collected at the border were attacking grubs in the immediate vicinity. A search during several seasons, however, failed to reveal more than an occasional individual of any host species in this locality, or in any other nearer than the pine forests in which the parasitized grubs had previously been found in numbers. It appears surprising, in view of the known habits of other members of the genus, for the females to travel through several miles of forest to an elevation nearly 1,000 feet higher for feeding and then to return for oviposition, but extended observations through several seasons substantiate the conclusion that these are the facts in the case.

LIFE HISTORY

There is a single generation of *Tiphia matura* each year, and the winter is passed in the adult stage within the cocoon in the soil. In the 1927 shipment of cocoons, arriving at Riverton, N.J., November 7, a considerable number of adults had emerged en route, and in the field a few may be found during the fall months of the warmer years. This species is evidently one which, under slightly more favorable climatic conditions, would produce two full generations each year.

The seasonal occurrence of the adults is dependent to a large extent on the time of the first spring rains. In 1927 the first individuals were found in the last week of April, the peak of abundance being attained during the third week in May. In 1928 it was very warm during the early spring, and the first rains fell during the middle of April. As a result the parasite began to emerge very much earlier than in the preceding season, the first females being collected on April 11. They were present in considerable numbers from April 16 to 20, at which time a sex ratio of 25 females to 1 male was noted—an abnormal condition, as with most species the reverse is true during the early

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part of the emergence period. After that date a decline set in owing to the cessation of the rains. The proportions of the sexes then became approximately equal. Increased emergence took place from May 1 onward, the peak occurring about May 12, and collection was continued until June 7. The adults were thus present in the field approximately 2 months, a considerably longer period than with the majority of species of Tiphia. It is probable that the long period of life and the relatively slow rate of oviposition are due to the previously discussed habit of traveling long distances for food, which does not permit of daily visits to the breeding grounds.

The egg of this species is placed ventrally on the abdomen in the groove between the eighth and ninth abdominal segments and near the lateral margin. The manner of feeding of the larva, and its development, correspond in all respects to those of other species studied.

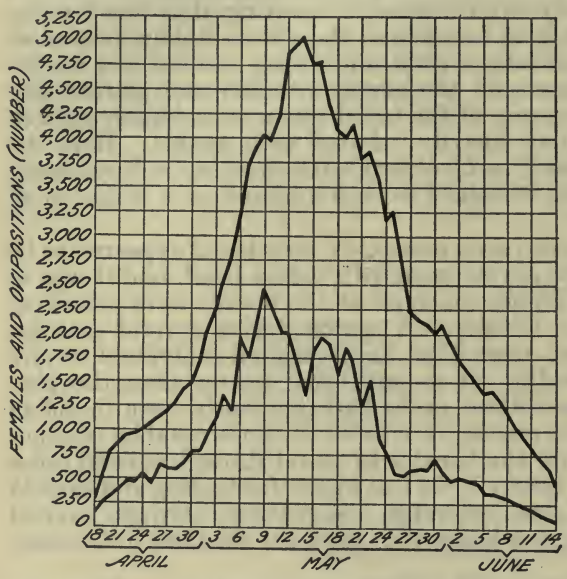

FIGURE 15.—Numbers of females of *Tiphia matura* in the rearing tins (upper curve) and the daily records of ovipositions (lower curve) during the 1928 season.

COLLECTION AND REARING RESULTS

In 1926, the first season in which extensive work was undertaken with this species, 8,005 ovipositions were obtained. These resulted in the formation of 2,712 cocoons, of which 470 were discarded owing to attack by fungus.

From May 5 to June 17, 1927, 12,606 females were collected and from these 44,562 ovipositions were obtained, resulting finally in the production of 13,407 cocoons.

Figure 15 shows the number of females of *Tiphia matura* in the breeding cages each day during the period in 1928 in which they could be secured in numbers in the field, and the daily record of ovipositions obtained from them under laboratory conditions.

The collection work was started on April 13 and continued daily, with the exception of 5 days of heavy rain, until June 7. The maximum number of females in the cages at one time was 5,054 on May 14, which date, or a few days earlier, represented the numerical peak of female abundance in the feeding areas. The greatest number of eggs deposited in a single day was 2,467, from 4,033 females, and the number of ovipositions from 12,518 females during this entire period was 53,897. The general average was 0.39 egg per day per female, as compared with 0.27 in 1926 and 0.4 in 1927.

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From these eggs, largely upon *Popillia cupricollis*, there was finally obtained a total of 16,249 cocoons, a percentage of 30.1, the same as in 1927, as compared with 33.9 in 1926.

The methods of rearing *Tiphia matura* in the laboratory were in general the same as those previously employed with various other species in Japan and Chosen, except for modifications in the handling of the grubs following parasitization. The soil available for use in the breeding trays dried out and pulverized very quickly, and the direct application of water to these trays during the development of the Tiphia larvae often resulted in some loss through the collapse of the grub cell. This was prevented by the use of burlap covers over each tray, which were soaked in water at necessary intervals. This moisture seeped down into the soil in a more natural manner and maintained a higher and more favorable humidity as well.

The unsatisfactory physical condition of the soil, however, led finally to the use of freshly chopped moss as a substitute, with a resultant increase of 10 to 15 percent in the yield of cocoons.

SHIPPING METHODS

The cocoons were permitted to remain in the original cells in the breeding trays until the time for shipment, when they were transferred directly to the containers and forwarded. Owing to the long period en route, usually from 40 to 50 days, it was necessary to devise special methods of packing, both to insure an adequate humidity in the cases and to eliminate so far as possible the spread of fungous infection from one cocoon to another.

During the earlier investigations on this and other species it had been believed that the fungus present was developing on the bodies of dead larvae only, but later its true pathogenic nature was established. In transferring cocoons it consequently became necessary to employ frequently sterilized forceps to prevent the spread of spores by contact, and to separate the cocoons more widely in the shipping containers.

The earlier consignments were packed in tin containers inclosing heavy paper or celluloid cross-section blocks, of the type used in commercial egg crates, with one cocoon placed in each section. The tins were packed in moss in wooden cases. This maintained the moisture content, but a heavy loss resulted through fungus spreading in the tins.

The shipping containers later employed included wooden trays 15 inches square and 2 inches deep, fitted with cross-section sets providing compartments 1 inch square and 2 inches deep. Two cocoons were placed in each compartment, each cocoon being surrounded with moss, and separated from the other by a square of tin or celluloid. The trays, holding 450 cocoons apiece, were then packed in sets of five, surrounded by a layer of fresh sphagnum moss, in large wooden cases.

This method of shipment resulted in the reduction of loss from fungus to 2.4 percent in a total of 15,750 cocoons forwarded in 1928, as compared with 74 percent loss in the 1927 shipment of 9,300 cocoons. In the latter shipment 426 adults had emerged in the cases prior to arrival at Riverton, which would indicate that the temperature in the cases must have been exceptionally high in transit, as other consignments forwarded at normal temperatures did not show this emergence.

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The total shipments of *Tiphia matura* from India during the years 1925 to 1928, inclusive, comprised 27,470 cocoons, practically all of which were reared from field-collected females.

Tiphia biseculata A. and J.

GENERAL OBSERVATIONS

Tiphia biseculata is normally a parasite of a species of Anomala, but it will develop readily upon *Popillia japonica*. It was first encountered in 1920 and was tested at that time on the latter host, but the percentage of mortality in the egg and early larval stages was so great as compared with other species that it was assumed that this host was unsuitable. It was later discovered, however, that this loss occurred also on the native host under similar conditions, and that development upon Popillia was fully as good as upon Anomala.

Tiphia biseculata has been found to date only in a single locality in Schizuoka-ken, Japan, in a small, sandy peninsula jutting out a few miles into the sea near Shimizu, which has an exceptionally temperate climate as compared with that of the inland areas.

LIFE HISTORY

Owing to the very favorable climatic conditions prevailing in its native habitat *Tiphia biseculata* is able to develop two full generations each year. This and *T. tegitiplaga*, occurring in the same locality, are the only species encountered in Japan and Chosen having this habit. As the soil contains a very high proportion of sand the soil temperatures are relatively high, and insect activity is extended over a longer period during the year.

The adults of the spring generation appear in the field throughout June and those of the second from late August to the end of September or to early October. Hibernation is in the adult stage in the cocoon. The first brood feeds entirely on the honeydew voided by aphids infesting melon vines and other truck crops, whereas the second feeds very largely at the nectar glands found at the base of the leaf petiole of sweetpotato, at the blossoms of buckwheat, and at times extensively upon the secretions of the pine aphid. The first brood is much more numerous than the second.

The egg is laid ventrally in the suture between the third thoracic and the first abdominal segments, with the anterior pole directed toward the lateral margin of the host. This position may vary to a certain extent, some being found one segment farther caudad, and others may be placed in the median suture between the last pair of legs. In the normal position it is not situated so near the lateral margin of the host body as is the egg of certain other species, the anterior pole being usually at the inner base of the hind leg. The host grubs used in the rearing work were *Anomala* spp.

The duration of the egg stage is 4 days in June and 5 in September, and the larval feeding period, to the formation of the cocoon, occupies 18 days in the first generation and approximately one month in the second, owing to the much lower temperatures of late September and October.

The maximum number of eggs secured from a single female of *Tiphia biseculata* in captivity was 38, the average being 19.6 for the

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several thousand females in the breeding series, which had an average length of life of 13.1 days. The egg production per day per female was thus comparable to that obtained with *T. popilliavora* at Koiwai (*6*).

REARING METHODS

The methods used with *Tiphia biseculata* were identical with those previously employed with *T. popilliavora* and *T. vernalis*. To eliminate so far as possible the high rate of mortality due to the loss of the lightly attached eggs and early-stage larvae through the movements of the host grubs in the sandy soil available at Miho, a quantity of light loam was secured for use in the breeding tins. As a result of this change the proportion of cocoons obtained from the eggs laid increased from 20.5 percent in 1925 and 20.1 percent in 1926 to 30.3 percent in 1927. This is still a very low figure as compared with those for many of the other species studied, and is very largely due to the comparatively light attachment of the early stages, as previously described. The greater activity of the host grubs in the rearing tins, as compared with that under natural conditions in the field, makes this loss unavoidable.

As the rearing work was done late in the season (early October and November) the normal insectary temperatures were not sufficiently high to bring the larvae to maturity, and it was consequently necessary to provide heated quarters for the rearing trays.

SHIPMENTS

During the years 1924 to 1928, inclusive, 13,033 cocoons of *T. biseculata* were forwarded to the United States, all of which had been reared from females of the second broods. A consignment of 1,000 adult females, forwarded October 4, 1926, and arriving at the Riverton laboratory October 21, showed a survival of 111, or 11.1 percent, but the field temperatures in New Jersey at that time of the year were so low as largely to inhibit activity and oviposition by the parasites. The 1928 shipment of 2,651 adults was from the first brood, and arrived in New Jersey on July 2, after being 19 days en route. Only 106, or 4 percent, were alive, these being among the last collected in the field prior to being forwarded. The very high mortality in this instance was probably due to the high temperatures prevailing during transit across the United States. The season of the year at which the first brood of adults must be forwarded thus makes this method of shipment impracticable, whereas the consignments of the second arrive too late to be of value, consequently the rearing and shipping of cocoons has been the more satisfactory method of dealing with this species.

TIPHIA PULLIVORA A. AND J.

GENERAL OBSERVATIONS

Large numbers of *Tiphia pullivora* have been found in the Khasi Hills of Assam, India, at an elevation of 4,800 to 5,200 feet. The adults appear in the field from late July to early October and feed at various blossoms and nectar glands and on the honeydew from aphids. The principal host under normal field conditions is an undetermined ruteline species of rather small size, while an occasional individual of *Popillia cupricollis*, in the second or early third stage, and another

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species of Popillia also, were attacked. The egg is laid ventrally between the second and third abdominal segments with the anterior pole directed toward the lateral margin. In the laboratory a series of females was tested upon half-grown grubs of *P. cupricollis* and found to develop satisfactorily. In view of this it was thought that the species might serve against *P. japonica* in America, particularly on the grubs too small to accommodate properly the other fall species of Tiphia already imported from Japan, Chosen, and China.

Extended experimental work with this species on grubs of *Popillia japonica* in the United States indicates, however, that it is able to develop only with difficulty on this host, and all field colonizations have failed to establish themselves.

The normal host of *Tiphia pullivora* was very abundant in the waste areas in the hills sections, inhabiting fallow agricultural lands, lightly forested hillsides with rather sparse undergrowth, and sod along forest pathways and roads. The field parasitization in some localities was found to range as high as 27 percent—an exceptional condition with Tiphia and unusual in the case of any parasitic insect in Assam.

FIELD COLLECTIONS

Because of the abundance of host grubs and the percentage of parasitization, large numbers of cocoons of *Tiphia pullivora* could be collected in the field, and consequently rearing work for obtaining these was rendered unnecessary. Practically all larvae had spun the cocoon by the middle of October, and collections of these could be made during the following two or three months for winter shipments and in May, June, and early July for forwarding to arrive in the United States just prior to the time of normal emergence.

As the cocoons are very small and delicate, considerable loss occurs through mechanical injury at the time of collection. With a cocoon of this type it is usually difficult, in fact impossible, to detect through external evidence whether such injury has occurred, unless the cocoon is very noticeably crushed. The truer indication is the early development of fungus on the body of the larva and the subsequent envelopment of the cocoon by the mycelium.

During the period of collection the cocoons as soon as found were set aside in trays under as nearly uniform conditions of temperature and humidity as possible. They were then examined at frequent intervals and those showing fungus development discarded to prevent its spread to other cocoons.

A general average of about 100 cocoons per day could be found by each of the collectors, and the number of these employed ranged up to 20 at certain times. Digging was extended over a period of several months each year.

With the cocoons of *Tiphia pullivora* in the field there was intermixed a varying proportion of those of *T. capillata* A. and J. and *T. levipunctata* A. and J. As there was no means by which these could be distinguished, the entire lot was included in the shipments. Separation of adults could be readily made at the time of emergence, as the latter two species are characterized by the reddish coloration of the legs.

SHIPMENTS

The first consignment of these cocoons, comprising 5,300, was forwarded in November 1925, half being placed individually in gelatin capsules and half in paper cross-section sets in tin containers. The

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apparent condition of this lot on arrival indicated that 93 percent were alive, and in a following shipment of 8,660 in March 1926, of the same generation, 65 percent were alive. No emergence was secured from this material, however, a portion living through the second winter and then dying. In all of the following winter shipments this tendency to carry over to the second season has been noted.

The summer collections, forwarded so as to arrive in the United States just prior to the emergence of the adults, were always in less satisfactory physical condition than those sent during the winter. The shipments of 1926, which were sent by mail and were 56 to 61 days en route, resulted very unsatisfactorily. In 1928 the date of forwarding the summer shipment was further delayed and cage provision made for emergence en route, an agar preparation being supplied as food. The cages were placed in the vegetable chamber of the steamer from Calcutta, having an approximate temperature of 40° F. About 12 percent of a total of 7,539 emerged en route in spite of the relatively low temperature, but only one of these was alive upon arrival. The remaining cocoons were of doubtful vigor.

Shipments during the summer were finally abandoned and efforts concentrated on those sent during the winter. The increased care in handling, to reduce fungous attack, during collection and storage, in conjunction with the improved methods of storing devised at the Riverton laboratory, have resulted in a fairly adequate emergence of adults from the more recent consignments.

The total number of field-collected cocoons shipped to the United States during the years 1925 to 1928, inclusive, was 93,815, of which a varying proportion were of species other than *Tiphia pullivora.*

Tiphia brevilineata A. and J.

Tiphia brevilineata has thus far been found only in the vicinity of Suigen, Chosen, and in rather limited numbers. It is normally parasitic on the grubs of *Anomala sieversi* Heyd., and *Phyllopertha pubicollis* Waterh., but in the laboratory it was found to oviposit and develop readily upon *Popillia mutans.*

The adults appear in the field throughout July and till the middle of August and feed upon the liquid excretions of aphids and other bugs. One generation is produced each year, and the winter is passed in the larval stage in the cocoon.

The egg is at first translucent white, later taking on a yellowish tinge. It is placed ventrally between the third and fourth abdominal segments of the host grub, near the lateral margin, and with the anterior pole directed outward. Hatching occurs in 3 or 4 days, and the cocoon is spun from 12 to 15 days later under maximum temperature conditions in Chosen. The outer covering of the cocoon forms a distinct envelope.

In 1925, laboratory ovipositions numbering 140 were obtained, from which 75 cocoons developed and were shipped to the United States. Owing to the scarcity of adults in the field in the known collecting areas, it has not been possible to carry on extensive rearing work with this species.

Tiphia notopolita A. and J.

Tiphia notopolita has been found in relatively small numbers in the Provinces of Chekiang, Kiangsu, and Fukien in China, and has also

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been taken at Yokohama, Japan, and Suigen, Chosen. Its normal hosts in China are *Popillia chinensis* Friv. and *P. formosana* Arrow.

The adults appear in the field in late August and may be found until the middle of October, this period varying somewhat in the different localities in which the species is found.

The egg is laid ventrally between the eighth and ninth abdominal segments of the host, the anterior pole toward the lateral margin. The duration of the egg and larval stages combined was found to be approximately 20 days at normal temperatures in September and early October, this being reduced to 15 days when the rearing trays were kept in a room heated to from 60° to 70° F.

Owing to the scarcity of adult females and the small percentage of eggs which developed, only 33 cocoons were obtained during the two seasons.

Tiphia communis A. and J.

Like *Tiphia notopolita*, *T. communis* has been found in China in the Provinces of Chekiang, Kiangsu, and Fukien, but in some numbers. In the field it is parasitic upon various ruteline grubs, mainly of *Miridiba trichophorus* Fairm., and experimentally has been found to reproduce readily upon *Popillia formosana*. At Penniu, in 1926, an examination of over 15,000 field-collected Popillia grubs showed a parasitization of 0.57 percent, while 1.15 percent of those of *Autoserica* sp. were found to bear eggs or larvae of this species. At times Adoretus is also a host of this species.

Two generations are produced each year, the adults of the first appearing in the field from the middle of June to the end of July, whereas those of the second are present from early August to the end of September, the peak of numerical abundance of females being July 7 to 19 and September 9 to 21, respectively. At Penniu they persisted in the field until November. The adults of both broods feed at the blossoms of wild carrot and other weeds.

The egg is pure white when laid but assumes a grayish or brownish tinge before hatching. It is placed dorsally between the second and third thoracic segments, with the anterior pole toward the median line.

The egg stage occupies 8.5 days, and 11 or 12 days are required for the development of the larva to the formation of the cocoon. The cocoon stage of the summer generation was found to be 36 days. The incubation period as compared with the larval stage is exceptionally long, particularly in view of the high temperatures prevailing during June in the area of investigation.

In the breeding work in various localities in 1925, 4,155 ovipositions were secured, from which 1,256 cocoons resulted, a percentage of 30.2.

The value of this species as a parasite of *Popillia japonica* in the United States will depend on the effect of the new climatic conditions upon its annual cycle. If these changed conditions result in only a single generation in the early spring, it will be of value; but the retention of its original time of emergence would render the first generation valueless and unable to reproduce itself through the lack of host grubs.

A small consignment of adult females was forwarded in July 1925, but all were dead on arrival; however, during this and the following season 1,480 reared cocoons were shipped.

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Tiphia assamensis A. and J.

Tiphia clauseni A. and J.

Two species of Tiphia were found to occur in very small numbers during the spring months in Assam, India, *T. assamensis* and *T. clauseni*. The former is parasitic on the mature grubs of *Popillia cupricollis* and places its egg ventrally between the second and third abdominal segments. *T. clauseni* attacks the grubs of an undetermined species of Popillia. The egg position is dorsal between the second and third thoracic segments. Owing to the very small numbers available, no rearings for shipment could be made.

Tiphia Sp.

Adults of an undetermined species of Tiphia, which were found feeding at the blossoms of various umbelliferous plants, were collected in the field at Taihoku, Taiwan (Formosa), in September 1927. The normal host in the field was not determined, but insectary tests showed that it oviposited and developed very readily upon Popillia grubs, and it is probable that some member of the genus is the true host.

The egg has a yellowish tinge, and is placed ventrally between the seventh and eighth abdominal segments. The egg and larval stages cover 3 or 4 and 12 to 15 days, respectively.

MISCELLANEOUS SCOLIIDAE

In view of the establishment in recent years of infestations of *Anomala orientalis*, *Autoserica castanea*, and *Serica similis* in the eastern part of the United States from the Asiatic regions, it has become necessary to investigate the possibility of effecting the introduction of their natural enemies. In addition to *Tiphia biseculata*, *T. brevilineata*, and *T. koreana*, which have been discussed as possible Popillia parasites, though attacking Anomala under normal conditions, the following species have been studied and shipments made to the United States:

Parasite	Host	Country
Tiphia bicarinata Cameron	Anomala, Phyllopertha	Japan, Chosen, China.
Tiphia totopunctata A. and J.	Anomala, Phyllopertha	Chosen and China.
Tiphia agilis Smith	Serica	Japan, Chosen, China.
Tiphia ovidorsalis A. and J.	Serica	Chosen.
Tiphia asericae A. and J.	Serica	Japan, Chosen, China.
Tiphia notopolita alleni A. and J.	Phyllopertha	Chosen and China.
Tiphia malayana Cameron	Adoretus	China.
	Serica	Chosen.

Tiphia bicarinata Cameron

Tiphia bicarinata was found in very small numbers in Japan and in Fukien, China, but was abundant at Suigen, Chosen. It is a normal parasite of the grubs of *Anomala sieversi* and *Phyllopertha pubicollis* and should prove adaptable to *A. orientalis* in the United States.

The adults appear in the field from early in August to the middle of September and feed at the blossoms of various Umbelliferae. A single generation is produced each year, and the winter is passed in the larval stage within the cocoon.

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The egg is pale yellowish and is placed ventrally between the third and fourth abdominal segments of the host grub, or occasionally one segment away in either direction, with the anterior pole directed laterally. The egg and larval periods cover 3 and 12 to 20 days, respectively, under relatively high temperature conditions. The cocoon of this species may be readily distinguished from that of all others of the genus studied by its glazed outer surface and by the almost complete lack of the web of silken strands which usually surrounds cocoons of Tiphia.

Although with most species of Tiphia a second oviposition on a grub already parasitized results in the loss or breakage of the first egg laid, this does not necessarily take place with *T. bicarinata*. Very frequently grubs have been found in the field bearing 2 or 3 eggs, and one was observed with 6. Also it has been noted that 2 larvae will develop side by side on the same host grub and eventually spin normal cocoons. With other species the result in such cases is usually the death of both larvae. Under laboratory conditions a maximum of 6 eggs was laid in 1 day by a single female.

In 1925, 1,200 ovipositions resulted in 726 cocoons, giving the exceptional percentage of 60.5 developing to that stage. The 1926 breeding work resulted in 9,982 eggs, from which 5,824 cocoons, or 58.3 percent, were secured. Shipments of reared cocoons to the United States to the end of 1928 totaled 5,720.

Tiphia totopunctata A. and J.

One of the species which was secured in relatively small numbers at Suigen, Chosen, in 1925 and 1926 was *Tiphia totopunctata*. It is recorded also from Szechuen, China. It is parasitic upon the grubs of *Anomala sieversi* and *Phyllopertha pubicollis*.

The adults may be found in the field from the early part of July to the latter part of August feeding upon the honeydew of aphids and other bugs. There is a single generation each year, and hibernation is in the mature larval stage.

The egg is dark brown and is placed dorsally on the third thoracic segment, with the anterior pole toward the median line. Under fairly high temperature conditions the incubation period is 5 or 6 days, and the development of the larva to the spinning of the cocoon requires 18 to 20 days. The outer covering of the cocoon forms a distinct envelope readily separable from the cocoon itself.

Owing to the scarcity of adults, only 245 ovipositions were secured in 1925, of which 35 developed to the cocoon stage. In 1926, material was somewhat more abundant, and 1,307 ovipositions yielded 605 cocoons, a development percentage of 46.3. Of these cocoons, 446 were shipped to the United States for colonization.

In view of the late appearance of the adults in the field, it is questionable whether this species will be of value against *Anomala orientalis* in the United States, as the time of their appearance very nearly coincides with the emergence of the beetles in the infested section.

Tiphia agilis Smith

Tiphia agilis was found most commonly at Suigen, Chosen, but has also been taken in various localities in central Japan and at Kuliang, China. It is parasitic upon *Serica orientalis* Motsch. and others of that genus which are in the mature larval stage late in the summer.

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The adults appear in the field about the middle of July and persist until the latter part of August. They feed on the honeydew of aphids occurring upon various species of oak, and at a variety of blossoms.

The egg, which is dark in color, is laid ventrally between the third and fourth abdominal segments of the host, with the anterior pole directed toward the lateral margin. Hatching occurs in 3 or 4 days, and the larval feeding period is complete in 12 or 13 days at summer temperatures. The cocoon is of normal form and color, with the outer covering loose and not separable into layers.

From 178 eggs obtained in 1925 during the breeding work 122 cocoons were eventually formed, giving the exceptional development percentage of 68.5. Total shipments during that and the following year comprised 197 cocoons.

Tiphia ovidorsalis A. and J.

A species parasitic on *Serica* sp. at Suigen, Chosen, *Tiphia ovidorsalis*, has not been noted in any of the other localities of investigation. The adults may be found in the field during August, and feed at the secretions of aphids and other bugs.

The grayish egg is placed dorsally on the third thoracic segment of the host grub, with the anterior pole directed toward the median line. Incubation requires 3 or 4 days and the larval feeding stage 11 to 14 days.

Owing to the limited numbers of females available in the field, extensive insectary rearings were not possible. In 1925 and 1926 only 99 cocoons were secured for shipment to the United States.

Tiphia asericae A. and J.

Tiphia asericae has been recorded from Iwateken, Japan, Keikido, Chosen, and Chekiang, China, and was by far the most abundant in the Chosen area. It is parasitic on various species of sericine grubs which attain maturity during the late summer and fall.

The adults appear in the field in Chosen early in June and persist to the end of that month or the first part of July. Feeding occurs on the honeydew given off by aphids and other bugs infesting pine, oak, and chestnut trees.

The egg is laid laterally in the suture between the seventh and eighth abdominal segments, just above the spiracle of the eighth segment, with the anterior pole directed toward the median dorsal line of the host. The incubation period covers 3 days, and the larva completes feeding and spins the cocoon from 10 to 12 days later, this being under the high-temperature conditions prevailing during June in Chosen. The winter is passed in the adult stage in the cocoon.

In the rearing work conducted at Suigen in 1927, 2,911 ovipositions were secured during the 11 days which could be devoted to this parasite. From these there finally resulted 947 cocoons, a percentage of 32.5, and of these 935 were forwarded to the United States.

Two shipments of adult females, totaling 9,604, were forwarded during the middle of June, 1928. Only 58 out of the 2,527 in the first consignment arrived alive, while none of the second lot survived. This result was in conformity with that secured with other species forwarded at the same season, indicating that the high mortality was due probably to the high temperatures prevailing during the period of transit across the United States rather than to faulty methods of

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shipment. Laboratory experiments and field observations also indicate that this species has a shorter normal adult life than is usual in the genus.

Tiphia notopolita alleni Roberts (T. notopolita intermedia A. and J.)

The variety *Tiphia notopolita alleni* (*14*) was found in relatively small numbers at Suigen, Chosen, in 1924 and 1925, and is recorded also from Penniu, Hangchow, and Kuliang, China. In Chosen it is parasitic primarily on *Phyllopertha conspurcata* Har., and some individuals attack *P. pallidipennis* Reitt. The adults appear in the field during the latter part of August and persist until the end of September. They feed very largely at the blossoms of Seseli.

The egg is placed ventrally between the seventh and eighth abdominal segments of the host grub, in the depressed area near the lateral margin, with the anterior pole directed outward. The duration of the egg stage is 4 or 5 days and that of the larval stage 15 to 17 days under September temperatures.

Owing to the scarcity of adults in the field, very little rearing work could be accomplished. Only 120 ovipositions were obtained, resulting in 42 cocoons, which were shipped to the United States.

Tiphia malayana Cameron

The distribution of *Tiphia malayana*, as determined in these investigations, includes the Provinces of Fukien, Chekiang, and Kiangsu in China, the greatest numbers being found at Zakow. It was found also at Suigen, Chosen.

There is a marked difference in a number of points in the life history and habits of the Chosenese and Chinese forms, and consequently they will be dealt with separately. From the biological data presented it would appear that two distinct species are involved.

The Chinese form is parasitic upon the grubs of *Adoretus* sp., but oviposits and develops readily upon *Popillia chinensis* also. The period of emergence of the adult wasps appears to be unusually protracted, as they are found in the field from the middle of April until August, the greatest numbers being present during the early part of May. The normal period, however, was determined as being from the middle of April to the end of May. The egg is gray and is laid between the second and third thoracic segments ventrally, with the anterior pole toward the lateral margin. The duration of the egg and larval stages is 8 and 20 days, respectively. A maximum of 24 eggs was obtained from one female in the breeding series; and from the 699 ovipositions obtained, mainly upon Adoretus grubs, 320 cocoons were formed, a percentage of 45.8.

In the Chosenese form the adults appear in the field during the latter part of April and are present until the middle of May, this being the first species of the genus to appear in the spring in Chosen. The adults feed largely on aphid honeydew and also at the blossoms of *Forsythia* sp. A single generation is produced each year, and the winter is passed in the adult stage in the cocoon. This form is parasitic on the grubs of various sericine species which are in the mature stage during the spring. The egg is white when first laid but assumes an amber tint before hatching. It is placed ventrally between the third and fourth abdominal segments of the host grub, with the

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anterior pole directed outward. The egg and larval stages cover 10 or 11 and 20 to 22 days, respectively, during the latter part of May. The cocoon is intermediate in color, and the outer covering is loose and not separated into layers.

SHIPMENTS

Of the Chinese form, 290 cocoons and 424 adult females were forwarded to the United States in 1925. Of the latter number, 32 arrived alive. The following season 792 females were shipped, of which 118 survived. No material was forwarded from Chosen.

REARING AND SHIPPING OF SCOLIIDAE

The methods of rearing Scoliidae in large numbers have been discussed in general in the preceding bulletin (*6*) on this subject. Certain slight modifications have been found necessary for some species, though these have been required to overcome temperature and soil conditions existing in the particular localities rather than from a difference in the requirements of the species themselves.

In table 5 is given a summary of the rearing results obtained with the different species of Tiphia which have been studied during the course of these investigations. Among those species with which extensive rearings were undertaken the average cocoon production, as based upon the total ovipositions, ranged from 25.9 percent in the case of the second generation of *T. biseculata* in Japan to 61.8 percent for *T. popilliavora* in China. In contrast to the latter record is the 33.5 percent obtained with the same species in Japan.

TABLE 5.—*Rearing results with various species of Tiphia*

Species	Country	Year	Ovipositions	Cocoons produced	Ratio of cocoons to ovipositions: By year	Ratio of cocoons to ovipositions: By species and source
			Number	*Number*	*Percent*	*Percent*
T. agilis	Chosen	1925	178	122	68.5	68.5
T. asericae	do	1927	2,911	947	32.5	32.5
T. bicarinata	do	1925	1,200	726	60.5	58.6
		1926	9,982	5,824	58.3	
T. biseculata (second generation)	Japan	1925	5,048	1,034	20.5	25.9
		1926	8,756	1,760	20.1	
		1927	18,069	5,474	30.3	
T. brevilineata	Chosen	1925	140	75	53.6	53.6
T. communis	China	1925	4,155	1,256	30.2	31.5
		1926	549	224	40.8	
T. malayana	do	1925	699	320	45.8	45.8
T. matura	India	1926	8,005	2,712	33.9	30.4
		1927	44,562	13,407	30.1	
		1928	53,897	16,249	30.1	
T. phyllophagae	China	1925	2,118	864	40.8	40.8
T. popilliavora	Japan	1920–1922	[1] 10,000	3,350	33.5	33.5
	China	1925	11,307	7,794	68.9	61.8
		1926	13,071	7,738	59.2	
		1927	15,799	9,306	58.9	
T. totopunctata	Chosen	1925	245	35	14.3	41.2
		1926	1,307	605	46.3	
T. vernalis	do	1923	5,785	2,350	40.6	47.3
		1924	10,963	5,566	50.8	
		1925	13,530	6,404	47.3	
		1926	18,355	8,255	45.0	
		1927	8,880	4,659	52.5	
	China	1926	440	249	56.6	56.6

[1] Approximate.

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Owing to the varying times of the year in which the different species of Tiphia occur in the field, it has been necessary to modify the manner of shipment with different species to accomplish successful importation of these parasites. The methods described below are those employed in the work in Japan and China, from which countries the time in transit ranged from 14 to 26 days. The manner of dealing with the Indian species, for which the shipping time extends to 40 or 50 days or even more, has been given in the discussion of the respective species.

SHIPPING COCOONS

It has been found necessary to reduce to a minimum the handling of cocoons prior to shipment to prevent infection by fungous diseases, and also to insure against the spread of these diseases among the cocoons during the period they must be in the shipping containers. Practically all shipments of cocoons are forwarded as soon as the last larvae in the rearing trays have matured. They are then from 2 to 4 weeks in transit to the United States and upon arrival at the laboratory are placed in the storage chamber for hibernation and for keeping until emergence the following season. The test applied for the determination of the physical condition of these consignments upon arrival was the opening of a series of cocoons and the noting of the general appearance of the larvae or other stages contained therein. If the decline in vitality is relatively far advanced the body becomes flaccid, the normal glistening integument becomes dulled, and the body contents assume a somewhat yellowish tinge.

In the shipments from Japan and China in 1925 and later two general methods of packing were employed. The first was the use of individual tin containers, much like the common salve boxes, of slightly less than 1 cubic inch capacity, in which the cocoon was placed, surrounded by a small quantity of slightly moist moss. The tins were then packed in moss in tight wooden boxes.

The second type of container used consisted of tin or wooden cross-section sets in which each compartment had the same volume as the above-mentioned individual tin. The cocoons were individually surrounded by moss in these sections, and the sets were separated from each other by tin sheets.

With both of these forms of shipping containers the physical condition of the immature stages in the cocoons at the time of arrival was good. The individual tins, however, present the one advantage of checking the spread of fungus in the event that too much moisture in the cases should induce its development.

SHIPPING ADULT FEMALES

In the extensive program for the shipment of adult females of *Campsomeris annulata* and the various species of Tiphia from Japan, Chosen, and China from 1926 to 1928 a variety of food materials were tested for keeping the wasps alive en route. The liquids provided in the shipping tins fulfilled two purposes, that of supplying food for the insects and that of maintaining a proper degree of humidity. It was essential that this food should remain in good condition throughout the time in transit, without fermenting or hardening.

In the early shipments the food was combined with the water in a weak solution, the ingredients being either sugar or honey. Later a semisolid food was used, with greatly improved results. This con-

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sisted of Japanese agar mixed with either liquid honey or sugar sirup in equal proportions. This mixture is liquid when heated slightly and cools into a semisolid of the consistency of soft rubber. It is poured when warm into tin-lined holes in blocks of wood wired to the inside of the container.

In figure 16 is shown a section of the container used successfully for shipping both Campsomeris and Tiphia. This tin is 6 inches in diameter and 10 inches high, with holes punched in the bottom for drainage.

In the bottom of the tin is first placed a half-inch layer of sphagnum moss, then about 2 inches of moist humous soil, and this is covered with another layer of sphagnum moss, over which is fixed a woven-wire screen of half-inch mesh to prevent the displacement of the soil in case the container is overturned. The bottle contains pure water only, and the lamp wick which leads up through the neck is surrounded by, and rolled into, a rather large mass of absorbent cotton, the whole being then covered with gauze and firmly tied. This provides a large absorption mass and an extensive surface area from which the wasps may drink without becoming entangled in the cotton, and guards largely against spilling. The top of the tin is covered with cloth, securely tied, or may be of perforated metal. The tins are packed in pairs in slatted screen cases.

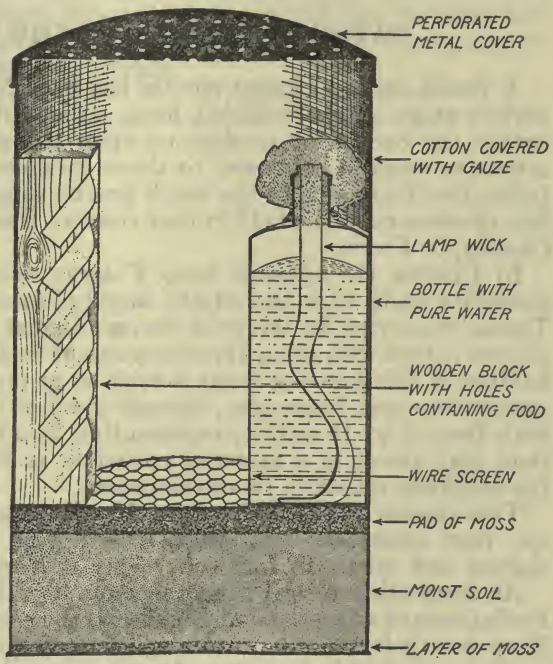

FIGURE 16.—Shipping container for adult Scoliidae, showing details of construction and contents.

The provision of soil in the containers is very desirable, as the wasps like to burrow about in it as they would under natural conditions. Moss alone does not give nearly so satisfactory results.

In table 6 are listed the various species of Scoliidae which have been shipped as adult females, with the period of collection and shipment, the numbers forwarded, and the percentage of survival. With Tiphia it is seen that in general the best results were secured with the spring species and that a very low proportion of those forwarded during the summer and fall were alive upon arrival.

With the majority of species, the shipment of adults rather than cocoons is much more satisfactory, both on the basis of cost and on that of results secured, provided the time in transit does not exceed 30 days.

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TABLE 6.—*Shipments of adult Scoliidae, 1925–28*

Species	Country	Period	Shipped	Survival	
			Number	*Number*	*Percent*
Campsomeris annulata	China-Japan	May-November	31,060	4,219	13.6
Tiphia asericae	Chosen	June-July	9,604	58	0.6
Tiphia biseculata:					
Spring generation	Japan	do	2,651	106	4.0
Fall generation	do	October	1,000	111	11.1
Tiphia communis	China	July-August	107	0	.0
Tiphia malayana	do	May-June	1,216	149	12.2
Tiphia popilliavora	Japan	August-September	2,249	65	2.9
Tiphia vernalis	Chosen	May-June	21,442	6,549	30.5

NATURAL ENEMIES OF THE SCOLIIDAE

A varied series of insect species has been found to prey on the immature stage of the Scoliidae, being either parasitic upon these stages within the cocoon or predacious upon the adult wasps. The more extensive records in regard to these enemies have been obtained in India, this being due to the much greater opportunities for the collection of cocoons in the field in that country than was the case in Japan, Chosen, or China.

In Chosen the sphecid wasp *Palarus saishiuensis* Okamoto (*15*) stores its nests with the adults, largely females of various species of Tiphia, occurring in the field during August and September, and to a lesser extent with other Hymenoptera of similar size. The restricted habitat of this hunting wasp is such as to prevent its being a serious enemy over any large area, though the fact that each cell is stocked with from 7 to 14 adults, representing usually a single day's collection, may result in a material reduction in the Tiphia population in the localities suited to its development.

Two species of mutillid wasps, *Mutilla stephani* Magr. and *Mutilla* sp., near *antennata* Sm., were reared from the cocoons of *Tiphia matura* and others in India, but only in very small numbers.

An interesting record from the same locality is that of a species of Perilampus as an occasional parasite in the cocoons of *Tiphia pullivora*. Each year a few adults of this species emerged from the many thousand cocoons collected for shipment to the United States. The planidium in some way, possibly after the cocoon is formed, gains access to the mature larva, to which it attaches itself externally, and development is completed upon the pupa.

A single species of rhipiphorid beetle, *Macrosaigon pusillum* Gerst., was reared from the cocoons of *Tiphia matura* and *T. pullivora*. Some collections of the latter species showed a maximum parasitization of 28.4 percent. The host is killed in the mature larval stage. The adults of this rhipiphorid show three color phases, some being entirely black whereas others have a red thorax or both thorax and abdomen red.

The bombyliid flies are common parasites of scoliid larvae. Three species, *Exoprosopa sipho* Ald., *Aphoebantus clauseni* Ald., and *A. seriatus* Ald., were reared in small numbers from the cocoons of *Tiphia pullivora*. An extended account has recently been published by the senior author (*5*) on the biology of a related species, *Hyperalonia oenomaus* Rond. The first-instar larva of the parasite gains access to the mature larva of the host in the cocoon, and development

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is completed upon that stage. This species was also observed to develop occasionally upon larvae of Scolia and Campsomeris.

The nematode *Eomermis tenuissima* Cobb was reared on several occasions from field-collected cocoons of *Tiphia matura* and *T. pullivora*.

SUMMARY OF PARASITE SHIPMENTS TO THE UNITED STATES

In table 7 is given the record of shipments of the various natural enemies of *Popillia japonica* and related species to the United States from the initiation of the project in 1920 to the end of 1928. There is also indicated the stage of development in which the material was forwarded, whether as immature larvae in living hosts, in the cocoon stage or as puparia, or as adult insects.

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TABLE 7.—*Record of shipments of parasite material to the United States for the control of the Japanese beetle, 1920–28*

Genera and species	Country	1920	1921	1922	1923	1924	1925	1926	1927	1928	Total
Tachinidae:											
Centeter cinerea, parasitized beetles, dead	Japan	95	118,000	144,000	50,000	50,000			142,000	99,400	603,495
Eutrixopsis javana, parasitized beetles, dead	do			210					78		288
Hamaxia incongrua, field-collected beetles, living.	do				6,500	20,700	37,400	25,200	42,100	166,100	298,000
Pyrgotidae:											
Adapsilia flaviseta, puparia	India							6,420	7,601	3,641	17,662
Dexiidae:											
Dexia ventralis, parasitized grubs	Chosen						850	8,624	11,850		21,324
Prosena sibirita—											
Parasitized grubs	Japan		800	7,800						5,000	13,600
Field-collected grubs	Japan				11,000	49,000	25,000	25,000	49,000		159,000
Scoliidae:											
Campsomeris annulata—											
Adult females	Japan, Chosen, China						9,199	21,861			31,060
Reared cocoons	Japan, Chosen, China				4	324	20				348
Parasitized grubs	Japan, Chosen, China						4,351	2,065			6,416
Tiphia agilis, reared cocoons	Chosen						105	92			197
Tiphia asericae—											
Adult females	do									9,604	9,604
Reared cocoons	do								935		935
Tiphia bicarinata, reared cocoons	do						720	5,000			5,720
Tiphia bisecutata—											
Adult females	Japan							1,000		2,651	3,651
Reared cocoons	Japan					98	1,030	1,760	5,323	4,822	13,033
Tiphia brevilineata, reared cocoons	Chosen						75	16			91
Tiphia communis—											
Adult females	China						107				107
Reared cocoons	China						1,256	224			1,480
Tiphia malayana—											
Adult females	do						424	792			1,216
Reared cocoons	do						290				290
Tiphia matura, reared cocoons	India						80	2,340	9,300	15,750	27,470
Tiphia notopolita, reared cocoons	China						17	16			33
Tiphia notopolita alleni, reared cocoons	Chosen							42			42
Tiphia ovidorsalis, reared cocoons	do						32	67			99
Tiphia phyllophagae, reared cocoons	Chosen, China						1,409				1,409
Tiphia popilliavora—											
Adult females	Japan, Chosen, China						1,030	1,219			2,249
Reared cocoons	Japan, Chosen, China	395	905	2,050			7,585	9,135	10,064		30,134
Tiphia pullivora, field collected cocoons	India						13,960	25,417	32,438	22,000	93,815
Tiphia totopunctata, reared cocoons	Chosen						30	446			476
Tiphia vernalis—											
Adult females	Chosen, China							4,325	9,868	7,249	21,442
Reared cocoons	Chosen, China					5,348	5,997	6,954	3,156		21,455
Carabidae:											
Craspedonotus tibialis, adult beetles	Japan	1,100	15,350								16,450

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AGRICULTURAL AND CLIMATIC CONDITIONS IN CHINA AND INDIA

In the previous publication (*6*) on the natural enemies of *Popillia japonica* in the Far East a short account was given of the agricultural conditions existing in Japan and their relation to the status of the beetle as an economic pest. The conditions in China and India, the new fields of investigation, are different in several respects from those of Japan, and call for some discussion.

The Popillia fauna of China is found largely in the low-lying valley lands of the Yangtze River from Nanking eastward to Shanghai and southward to Hangchow and Ningpo. The hilly areas between Chingkiang and Nanking, the mountainous district beyond Hangchow, as well as the other foothill and mountain sections which were scouted, do not provide suitable breeding grounds for this group of beetles. This is in contrast to the condition found to exist in India, where practically all species of the genus which were at all abundant were found in numbers only at elevations of 4,000 feet or more.

In the valley districts of the coastal Provinces of China intensive agriculture is practiced. Practically all of these districts are irrigated, the land being intersected by a complicated network of canals. Rice is the principal crop grown, with considerable cotton and large plantings of other small grains and various truck crops.

One of the distinctive features of any Chinese landscape is the relatively large area devoted to graveyards. Although these may often be situated on the less arable and rocky hillsides, a considerable portion of the more valuable valley land is taken by them. The burial mounds are usually surrounded by a border of grass 2 or 3 feet in width. This grass is kept closely cropped by cattle, the graveyards being of considerable importance as grazing areas owing to the lack of natural grasslands in these sections. These sod borders provide ideal breeding conditions for Popillia, and it was in such places, in the silt soil along the river and canal embankments, and in the small patches of sod along the paths and roadways that Popillia grubs could be found in numbers.

Of the Popillia fauna of the coastal sections of China, *Popillia chinensis*, *P. mutans*, and *P. formosana* were the most abundant in the valley districts, while *P. pustulata* was abundant in several of the mountain localities in the Provinces of Fukien and Kiangsi. The majority of the Chinese species of the genus appear to be foliage rather than blossom feeders.

The agricultural conditions in India differ markedly from those of Japan and China. The size of the country and its range in latitude, extending from near the Equator to the Himalayas, provide a great diversity in the crops grown and in the methods of cultivation. The plains areas, upon which the vast portion of the population lives, are very intensively cultivated. Throughout practically this whole plains region the annual rainfall is concentrated into a very few months in summer, resulting in an exceedingly arid condition during the winter. The intensive cultivation which is practiced does not permit of the development to numerical abundance of insect pests such as the genus Popillia, which largely inhabit waste lands. Also, the climatic conditions do not favor this genus.

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The hill sections of India, found in various parts of the country, particularly in the south, southwest, and northeast, provide a far different condition from that found in the plains, and one more nearly suited to Popillia, to judge from the relatively large number of species which occur in them. These hills range from 3,000 to 7,000 feet in height, and above 3,000 feet are usually covered with grass rather than with the jungle growth which characterizes the lower elevations. Although these hills are inhabited the population is relatively very sparse, and consequently only a very small portion of the land is under cultivation, and a considerable part of that which is arable is used for grazing. The climate is much more temperate, with the rainfall extending over a somewhat greater period than in the plains.

The Khasi Hills of Assam, in which section most of the work upon this project in India was done, attain a maximum elevation of about 6,000 feet. In the zone above 4,800 feet the Popillia fauna was found most abundant, and only occasional individuals could be found below that level. In the upper zone the vegetation is of a distinctively temperate rather than subtropical nature, and the hills are in part covered with pine forests, both natural and planted. The growth of these trees is not very luxuriant, and a light undergrowth of shrubs is usually present. This is induced to a certain extent by the practice of the natives of trimming away the lower branches of the trees for use as firewood. In the case of the cultivated lands the general practice is to permit the land to lie fallow for 1 or 2 years between crops. This fallow land provides an ideal habitat for the development of many scarabaeid species.

Of the 10 or more species of Popillia known to occur in the Khasi Hills, *P. cupricollis* and *P. cyanea* are the dominant forms. Like practically all species of the group, with the conspicuous exception of *P. japonica* and a few others, they confine their feeding almost exclusively to blossoms. The breeding areas of these two species are largely in the sparsely forested areas with a light undergrowth and a gravelly soil, and very few grubs could be found in open grasslands or in cultivated fields, though the adults frequently congregate there for feeding.

Various other sections in addition to the Khasi Hills were scouted for Popillia and its parasites. The Naga Hills in eastern Assam, which appeared to provide as suitable conditions as the Khasi Hills, revealed a very low Popillia population. The Nilgiri Hills in southern India presented more varied conditions than those of Assam, and a considerable number of species of Popillia are on record as occurring there, including one or two which at times become sufficiently abundant to cause injury to cultivated crops. In several trips to that section, however, no parasites were found. In July 1927 several weeks were spent in scouting in Kashmir, largely in the valley region (elevation approximately 5,000 feet) about Srinagar, and also in the near-by foothills to an elevation of 7,500 feet, but not a single representative of the genus was found during this period. It would appear that Kashmir is beyond the western limits of distribution of the Indian species.

Charts showing the monthly mean temperature and rainfall conditions at Sapporo, Koiwai, and Yokohama in Japan and at Suigen, Chosen, appear in the earlier publication (*6*) and those here given for comparative purposes are for Nanking, China, and Shillong, India.

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The collection and rearing of parasites in China took place at several widely separated points, but the Nanking conditions are taken as representative of the coastal belt in general.

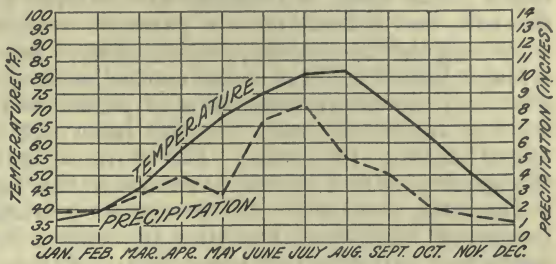

FIGURE 17.—Monthly mean temperature and average rainfall at Nanking, China, 1905–23.

The temperature curve (fig. 17) shows that Nanking (lat. 32 N.), though much farther south, has winter temperatures slightly lower than those of Yokohama (lat. 35.5 N.), and summer temperaturse slightly higher. The maximum monthly rainfall occurs in June and July, and the peak of the curve is considerably below that of Yokohama or Suigen (lat. 37 N.) and the annual total considerably less than that of either of the other two points mentioned.

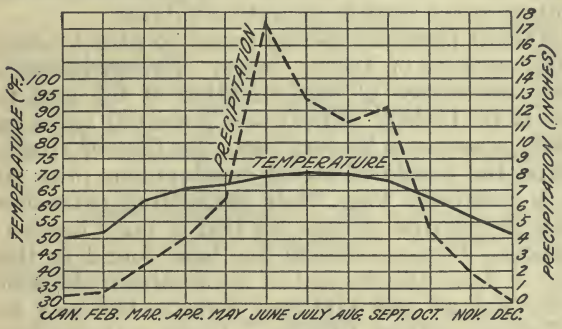

FIGURE 18.—Monthly mean temperature and average rainfall at Shillong, India, 1920–24.

The temperature curve for Shillong, India (lat. 25.5 N.) (fig. 18), differs from those of the other localities studied in that the winter temperature is considerably higher and that of the summer lower. The maximum rainfall is attained rather abruptly in June, and the precipitation during the following three months is fairly heavy, the annual total approximating that at Yokohama. With respect to minimum temperature and time of general rainfall, Shillong and Nanking conditions more nearly approach those of Yokohama than do those of any of the other fields of investigation.

In considering the temperature records for Shillong it is necessary to make allowance for the difference in interval between recordings. Here the monthly mean is based on the averages of three readings per day, at 9 a.m., 3 p.m., and 9 p.m., respectively, rather than the usual 2-hour intervals. On the latter basis the mean temperature would probably be slightly lower than that shown.

SUMMARY

The investigations, previously confined to Japan and Chosen (Korea), on the natural enemies of *Popillia japonica* have been extended to China and India.

Seven species of parasites have been found to attack *P. japonica* itself under natural conditions in Japan. Nine additional species have been found to parasitize different species of Popillia in the other.

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countries named and are adaptable to *P. japonica*. Of these 16 species, 5 species of Tachinidae and 1 of Pyrgotidae are parasitic in the adult beetle itself, 2 Dexiidae are internal parasites of the grubs in the soil, and 8 Scoliidae are parasitic externally on the same stage.

Among the Tachinidae, *Centeter cinerea* has maintained its status as a major limiting factor in the control of the beetle in northern Japan. The very extensive collections of parasitized beetles in the Sapporo section during the past 8 years have not appreciably reduced its effectiveness in that area. The southern limits of the distribution of the species are now known to extend to the Tokyo-Yokohama district.

Hamaxia incongrua (*Ochromeigenia ormioides*) has been found in numerous additional localities in central Japan, but with the percentage of parasitization exceedingly variable. Its favored habitat is much more restricted than that of the host, it being adapted largely to semiforested areas and waste land covered with a growth of shrubs, rather than to the cultivated fields.

Eutrixopsis javana, *Pexomyia genalis*, and *Trophops clauseni* have been found in exceedingly small numbers in Japan only, and are of no value in the natural control of the host in its native habitat.

Adapsilia flaviseta, the single pyrgotid species found to attack adult Popillia, occurs in the hill sections of Assam, India. Except in occasional very limited areas the extent of parasitization of the host is very slight. All factors in its biology indicate its potential value in the biological control of *P. japonica* to be very low. Its time of attack of the host is delayed and the period of larval development prior to the death of the host is relatively long, thus permitting extensive oviposition. The greater proportion of eggs are laid in male beetles.

Of the two dexiid species, *Prosena sibirita* has been found in the field from the early part of April till the end of September. It is of general distribution in the Asiatic and Malayan regions, but only in northern Japan is it of value against Popillia. *Dexia ventralis* has been found to have three generations each year when overwintering in Miridiba grubs and only two when that period is passed in Popillia. Both species have demonstrated the ability to develop to maturity in only partly mature grubs, though this is not the normal condition.

Among the eight species of Scoliidae parasitic upon the grubs of various species of Popillia, none has been found to have a uniform distribution comparable to that of its host; a high degree of parasitization is seldom found, and then only in very restricted areas. *Tiphia popilliavora* in Japan, *T. vernalis* in Chosen, and *T. matura* in India have shown the greatest field effectiveness in their native habitats. The eventual value of this group of parasites in the United States lies in the possiblity of having a series of these species rather than any single one of them. The food supply of the adults is one of the most important factors affecting increase and distribution.

Five additional species of Scoliidae, comprising *Campsomeris annulata* and four species of Tiphia, have been found adaptable to Popillia in the absence of the normal hosts, which are various species of Anomala.

Owing to the recent establishment of *Anomala orientalis*, *Autoserica castanea*, and *Serica similis* in the eastern part of the United States, studies of their natural enemies have been undertaken in Japan and Chosen.

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During the years 1920 to 1928, inclusive, extensive shipments were made of many species of parasites. Among these, 603,495 beetles parasitized by *Centeter cinerea* were collected and shipped, of which about 90 percent contained puparia, while 298,000 live *Popillia japonica* beetles containing a variable percentage of *Hamaxia incongrua* were forwarded, both species from Japan, and also 17,662 puparia of *Adapsilia flaviseta* from India. Of the Dexiidae, 21,324 grubs parasitized by *Dexia ventralis* were shipped from Chosen, and 13,600 parasitized by *Prosena sibirita*, as well as 159,000 field-collected grubs having an average parasite content of about 10 percent, were sent from Japan. Shipments of 17 species of Scoliidae have been made from Japan, Chosen, China, and India, comprising 69,334 adult wasps, 103,212 reared cocoons, 93,815 field-collected cocoons, and 6,416 parasitized grubs.

In the importation of scoliid parasites it has been found that, with the majority of species, the shipment of adults rather than cocoons is much more satisfactory, both on the basis of cost and of results secured, provided the time in transit does not exceed 30 days.

LITERATURE CITED

(1) Aldrich, J. M.
1928. FIVE NEW PARASITIC FLIES REARED FROM BEETLES IN CHINA AND INDIA. U.S.Natl.Mus.Proc. 74, art. 8, 7 p.

(2) Allen, H. W. and Jaynes, H. A.
1928. PROGRESS WITH THE IMPORTED PARASITES OF THE JAPANESE BEETLE DURING 1927. Jour. Econ. Ent. 21: 823–832, illus.

(3) ——— and Jaynes, H. A.
1930. CONTRIBUTION TO THE TAXONOMY OF ASIATIC WASPS OF THE GENUS TIPHIA (SCOLIIDAE). U.S.Natl.Mus.Proc. 76, art. 17, 105 p., illus.

(4) Burrell, R. W.
1931. DEXIA VENTRALIS ALDRICH, AN IMPORTED PARASITE OF THE JAPANESE BEETLE. Jour. Agr. Research 43: 323–336, illus.

(5) Clausen, C. P.
1928. HYPERALONIA OENOMAUS ROND., A PARASITE OF TIPHIA LARVAE (DIP., BOMBYLIIDAE.) Ann. Ent. Soc. Amer. 21: 642–658, illus.

(6) ——— King, J. L., and Teranishi, C.
1927. THE PARASITES OF POPILLIA JAPONICA IN JAPAN AND CHOSEN (KOREA), AND THEIR INTRODUCTION INTO THE UNITED STATES. U.S.Dept.Agr.Bul. 1429, 56 p., illus.

(7) Davis, J. J.
1919. CONTRIBUTIONS TO A KNOWLEDGE OF THE NATURAL ENEMIES OF PHYLLOPHAGA. Ill. Nat. Hist. Survey Bul. 13, art. 5, p. [53]–138, illus.

(8) Fiske, W. F.
1910. SUPERPARASITISM: AN IMPORTANT FACTOR IN THE NATURAL CONTROL OF INSECTS. Jour. Econ. Ent. 3: 88–97, illus.

(9) King, J. L.
1931. THE PRESENT STATUS OF THE ESTABLISHED PARASITES OF POPILLIA JAPONICA NEWMAN. Jour. Econ. Ent. 24: 453–462, illus.

(10) ——— Allen, H. W., and Hallock, H. C.
1927. THE PRESENT STATUS OF THE WORK ON THE PARASITES OF POPILLIA JAPONICA NEWMAN. Jour. Econ. Ent. 20: 365–373.

(11) ——— and Hallock, H. C.
1925. A REPORT ON CERTAIN PARASITES OF POPILLIA JAPONICA NEWMAN. Jour. Econ. Ent. 18: 351–356, illus.

(12) ——— and Holloway, J. K.
1930. THE ESTABLISHMENT AND COLONIZATION OF TIPHIA POPILLIAVORA, A PARASITE OF THE JAPANESE BEETLE. Jour. Econ. Ent. 23: 266–274, illus.

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(13) King, J. L. and Holloway, J. K.
1930. TIPHIA POPILLIAVORA ROHWER, A PARASITE OF THE JAPANESE BEETLE. U.S.Dept.Agr.Circ. 145, 12 p., illus.

(14) Roberts, R.
1930. SEVEN NEW NAMES IN THE GENUS TIPHIA (HYMENOPTERA, SCOLIIDAE). Canad. Ent. 62: 189–190.

(15) Sato, S.
1926. [SOME OBSERVATIONS ON PALARUS SAISHUENSIS OKAMOTO.] Kontyu 1 (1): 36–39. [In Japanese.]

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

THE USE OF WINTER LEGUMES IN THE SOUTHEASTERN STATES

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INTRODUCTION

The primary purpose of planting winter legumes in the South is to enrich the land; they are plowed down in the spring to fertilize corn, cotton, and other crops. The secondary use of winter legumes is for hay and grazing and the prevention of soil erosion.

"Winter legumes" usually mean those legumes that are planted in the fall and that ripen about the same time as winter wheat or oats. In the Southeast, hairy vetch (*Vicia villosa*) has led all other winter legumes, with Austrian winter peas (*Pisum arvense*) a good second. Crimson clover (*Trifolium incarnatum*) stands third in importance in that area and southern bur clover (*Medicago arabica*) stands fourth. Sour clover (*Melilotus indica*), which is used as a winter legume in Louisiana and Arizona, volunteers naturally in the black lands of Alabama and Mississippi.

The need for improved methods of building up and maintaining the soil fertility of the Southern States is evidenced by the fact

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that in many fields corn yields are only 8 or 10 bushels an acre and cotton yields are frequently below 100 pounds an acre. Such low yields make it necessary to put an undesirably large part of the farm in corn or to buy a considerable part of the feed. Through the use of winter legumes it seems feasible and economical to increase the yields until the same quantity of corn can be produced on one half to two thirds of the acreage, thus releasing land and labor for other crops. It appears that the low average yield of corn in South Carolina can be nearly doubled on the same acreage and, after meeting the feed requirements of a 2-mule farm, leave from 200 to 300 bushels to sell or to feed to an increased number of hogs or cows. Similar opportunities exist in other Southern States. In North Carolina, the 5-year average (1926–30) yield of corn was 21 bushels per acre; in South Carolina, 15 bushels; in Georgia, 13 bushels; and in Alabama, 14 bushels.

Large quantities of nitrogenous fertilizer to be used on cotton are bought by farmers each year in North Carolina, South Carolina, Georgia, and Alabama. This means a large cash outlay, a part of which might be eliminated through the use of more winter legumes.

Using winter legumes to improve soils and increase the yields of subsequent crops is not a new practice, but only recently has the real worth of these legumes for this purpose become generally known. This bulletin describes the actual experience of farmers who have used these legumes in increasing soil productivity, and indicates the costs of using winter legumes and the benefits received from their use under actual farming conditions.

METHOD OF STUDY AND APPLICATION OF RESULTS

The data used in this bulletin were obtained from farmers who grew winter legumes for fertilizing cotton and corn. Of the usable estimates of acreage and yield, 125 were made in 1929 for crops of cotton and corn grown after winter legumes in 1928 and earlier, and 375 were made in 1930 for crops harvested in 1929 and earlier. In addition, 31 estimates for corn crops and 14 estimates for cotton crops were obtained for periods of 3 to 5 years.

Some reference is made to the experiments with winter legumes as fertilizers at a number of experiment stations, but since such tests were made on particular soils under particular climatic conditions it seemed desirable to supplement them with the experience of farmers who live on a great variety of soils and under varied climatic conditions.

Both large and small farms were visited and estimates were obtained from areas as small as 1 acre and as large as 100 acres. As a number of farmers grew both vetch and winter peas, and in some instances had two or more tracts of the same legume growing under different conditions, the five hundred 1-year estimates were furnished by 300 farmers.

Most of the data were estimates of the number of acres of corn and cotton and the yield per acre. The acreage and production of corn and cotton following winter legumes were stated by the farmer. Then for the same year and for adjacent land, or land of the same natural fertility, the yield of these crops without winter legumes was given. The latter crops are called "check" crops. Their yields were compared with or checked against the yield of the same crops following the legumes.

There were 264 estimates for corn and cotton after vetch, 193 after Austrian winter peas, 32 after crimson clover, and 11 after southern bur clover. The size of the vetch fields and winter-pea fields aver-

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aged, in each case, a little more than 12 acres. The crimson-clover and bur-clover fields averaged approximately 7 acres each.

TABLE 1.—*Number of fields, total acreage, and average number of acres per field of corn and cotton grown after specified kind of winter legume*

Item	Fields [1]		Average size of field
	Number	*Acres*	*Acres*
Corn after vetch	202	2,393	11.8
Cotton after vetch	62	818	13.2
Total or average	264	3,211	12.2
Corn after Austrian winter peas	129	1,568	12.2
Cotton after Austrian winter peas	64	922	14.4
Total or average	193	2,490	12.9
Corn after crimson clover	18	151	8.4
Cotton after crimson clover	14	93	6.6
Total or average	32	244	7.6
Corn after bur clover	4	33	8.2
Cotton after bur clover	7	44	6.3
Total or average	11	77	7.0
Total corn	353	4,145	11.7
Total cotton	147	1,877	12.8
Grand total or average	500	6,022	12.0

Estimates of yields obtained on farms in the various States were: North Carolina, 4 estimates for corn after crimson clover; South Carolina, 17 estimates of crops after vetch, 8 after winter peas, 20 after crimson clover, and 10 after bur clover; Georgia, 113 after vetch, 79 after winter peas, 8 after crimson clover, and 1 after bur clover; Alabama, 134 after vetch and 106 after winter peas. South Carolina, Georgia, and Alabama probably represent the greatest concentration of winter legumes.

[1] The word field in this case is used for the tract of land growing the legume.

After winter legumes the cornfields averaged 11.7 acres and the cotton fields 12.8 acres. In all the size groups shown in table 2 except in that ranging from 21 to 50 acres, the acreage per field for cotton and for corn was practically the same, indicating uniformity of conditions. Even in the excepted group the acreage per field for corn and for cotton differed by only about 10 percent.

TABLE 2.—*Number of estimates and total acres of winter legumes classified according to the number of acres per estimate*

CORN AFTER WINTER LEGUMES

Item	Item specified when size of field was—					Total
	1 to 5 acres	6 to 10 acres	11 to 20 acres	21 to 50 acres	51 to 100 acres	
Estimates ... number	136	112	55	43	7	353
Legumes ... acres	459	905	852	1,409	520	4,145
Acres per estimate	3.4	8.1	15.5	32.8	74.3	11.7

COTTON AFTER WINTER LEGUMES

Estimates ... number	59	34	31	18	5	147
Legumes ... acres	202	291	474	535	375	1,877
Acres per estimate	3.4	8.6	15.3	29.7	75.0	12.8

COTTON AND CORN AFTER WINTER LEGUMES

Estimates ... number	195	146	86	61	12	500
Legumes ... acres	661	1,196	1,326	1,944	895	6,022
Acres per estimate	3.4	8.2	15.4	31.9	74.6	12.0

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The vetch and winter-pea fields were larger than the fields of crimson clover and bur clover (table 1), probably because they were on larger farms. The two clovers were restricted to the piedmont and richer soils, whereas the vetch and winter peas grew in both the piedmont and the Coastal Plain. In the Coastal Plain the farms were much larger.

The relative acreages of the various winter legumes, as found in this study, agree in a general way with the relative importance of the legumes in the States and parts of States visited. The results of this study are useful to farmers in all farming sections of the States in which data were collected and to farmers in other Southern States that have a humid climate. Farmers in Mississippi, Arkansas, and north Florida are using winter legumes in increasing quantities and with good results. In Louisiana, the annual yellow sweetclover (*Melilotus indica*) is being used successfully as a winter legume.

The word vetch is here used to include hairy vetch (*Vicia villosa*), smooth vetch (*V. villosa* variety), and Monantha vetch. "Winter pea" means Austrian winter pea (*Pisum arvense*) and "bur clover" means southern bur clover (*Medicago arabica*). Hairy vetch has predominated in this area heretofore, but in the spring of 1930 the writers found a much larger acreage of smooth vetch than of hairy vetch in the States visited. Smooth vetch is a variety of hairy vetch that has little pubescence or few hairs; it is fully as desirable for this area as hairy vetch and is considered superior by some farmers. Monantha vetch is used only in the southern parts of the area because it will not stand very low temperatures.

INCREASED YIELD FROM USE OF WINTER LEGUMES

CORN

Agronomists and experienced farmers have generally agreed that winter legumes, when plowed down in the spring for corn, increase the yield of corn. The real question has been, How much are yields increased by the use of winter legumes under actual farming conditions, and to what extent do farmers benefit by their use after deducting all expenses incident thereto? The answer to the first part of the question will be found in table 3.

TABLE 3.—*Average yield of corn and cotton when grown with and without winter legumes preceding*

Legume	Acreage studied	Average yield of corn per acre				Acreage studied	Average yield of lint cotton per acre			
		After winter legume	Not after winter legume	Increase per acre			After winter legume	Not after winter legume	Increase per acre	
	Acres	*Bushels*	*Bushels*	*Bushels*	*Percent*	*Acres*	*Pounds*	*Pounds*	*Pounds*	*Percent*
Vetch	2,393	33.3	19.6	13.7	70	818	389	280	109	39
Austrian winter peas	1,568	34.8	20.4	14.4	71	922	356	271	85	31
Crimson clover	151	43.5	24.4	19.1	78	93	538	384	154	40
Bur clover	33	23.5	15.0	8.5	57	44	391	293	98	33
Total and weighted average	4,145	34.1	20.0	14.1	70	1,877	381	281	100	35

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The increase in yield of corn from 20 bushels per acre to 34.1 bushels (an increase of 14.1 bushels per acre) amounts to 70 percent. It would have been a little more than this, probably, if as large a quantity of nitrate of soda had been used on the corn grown after legumes as was used on that grown without a preceding crop of legumes. The increase varied somewhat with the kind of legume plowed under. The use of crimson clover gave the largest increase in corn yield and bur clover gave the least, with yields from the use of vetch and winter peas coming between. It is perhaps unsafe to say that crimson clover is a better fertilizer than the other winter legumes even though the figures seem to show it. Its acreage was relatively limited and its geographic location was confined mostly to the northern parts of South Carolina and Georgia. It would be popular on the piedmont soils, to which it is adapted, if dependable stands could be secured. Further efforts should be made to see whether skill in getting stands can be improved.

Acreage of bur clover was also small and there is chance for a larger error in the indicated corn yields than in the yields of corn grown after vetch and winter peas.

The difference between vetch and winter peas in increasing yields is probably not great. On the farms studied corn did better after winter peas and cotton after vetch, but it is doubtful whether the differences are significant.

The increases indicated in table 3 mean that many farmers can produce as much corn as they are now producing on a little more than one half the present acreage, or nearly twice as much as they are now producing on the present acreage. They can easily produce all the corn needed for home requirements on their present acreage and thereby reduce the feed bills to a nominal amount.

Use of these legumes does not necessarily involve change in the type of farming. It involves no change in the quantity or kind of labor employed except that the larger harvest will require a little more labor. No change in power or implements is involved except that larger teams and plows would help in some instances.

Estimates were made of the yield of crops for each year from 1925 to 1929, inclusive (table 4). The yield of corn varied from year to year; but, in general, the yields after winter legumes and the yields not after winter legumes varied together, indicating that the seasons affected each in a similar way. The yields were lowest in 1925 and highest in 1926 (fig. 1).

TABLE. 4.—*Average yield of corn and cotton per acre after winter legumes and without winter legumes, 1925–29*

Year grown	Corn				Lint cotton			
	Acreage studied	Yield after legumes	Yield not after legumes	Increase in yield	Acreage studied	Yield after legumes	Yield not after legumes	Increase in yield
	Acres	*Bushels*	*Bushels*	*Bushels*	*Acres*	*Pounds*	*Pounds*	*Pounds*
1925 [1]	204	32.2	16.6	15.6	31	341	298	43
1926	552	39.6	21.9	17.7	43	454	283	171
1927	390	34.0	19.0	15.0	122	334	246	88
1928	802	36.5	20.4	16.1	383	434	310	124
1929	2,197	32.0	19.8	12.2	1,298	368	276	92
Total and weighted average	4,145	34.1	20.0	14.1	1,877	381	281	100

[1] 3 estimates for corn and 1 for cotton grown in 1924 are included in the 1925 figures.

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Not every farm obtained an increase in yield from the use of winter legumes. There were failures as well as successes and various degrees

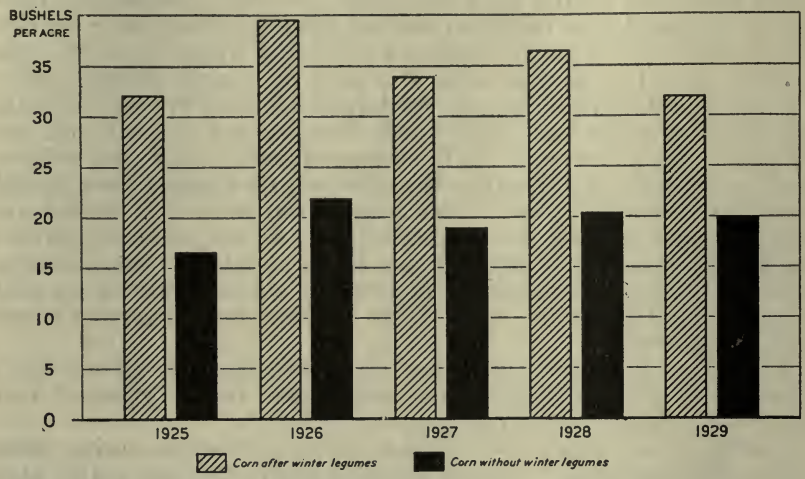

FIGURE 1.—YIELD OF CORN GROWN AFTER WINTER LEGUMES AND WITHOUT WINTER LEGUMES.

The year of the largest yield of corn after winter legumes and without winter legumes was in 1926 and the next largest was in 1928. Increased yields varied from year to year, but were profitable in all years.

of each. Variations in increase or decrease in yield are shown in table 10 (p. 16) and discussed in the text at that point.

In addition to the 353 fields of corn for which estimates were made, each for a specified year, there were 31 fields totaling 919 acres for

FIGURE 2.—Hairy vetch on a farm near Trenton, S. C., May 6, 1929. A crop of corn following this vetch yielded 105 bushels an acre. The corn was fertilized with 400 pounds of nitrate of soda and 100 pounds of potash manure salts an acre. The vetch was not fertilized, but the land had been well farmed in previous years.

which the estimates represented average results for periods of 3 to 5 years. The average yields for these crops were 35 bushels per acre after legumes and 19 bushels not after them—a gain of 16 bushels per

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acre. Here, again, the experience of the farmers points to a tremendous gain in corn yield through the use of winter legumes.

As farmers have longer experience with winter legumes they will learn how to handle these crops, and will get better results; but even

FIGURE 3.—Corn after winter peas and not after winter peas near Ozark, Ala. Corn after winter peas, on right, yielded 50 bushels an acre. Corn not after winter peas, on left, yielded 28 bushels an acre. Corn on right was not fertilized directly, but 400 pounds of superphosphate per acre had been applied to the winter peas the preceding fall. On left, 300 pounds of nitrate of soda per acre were applied to the corn.

with the limited experience these men had they obtained increases that are of much significance (figs. 2 and 3).

TABLE 5.—*Average yield of corn grown after vetch and winter peas, by date of planting*

Date of planting corn	Winter legumes		Corn yields per acre		Increase in corn yield per acre
	Fields	Acreage	After legumes	Not after legumes	
	Number	*Acres*	*Bushels*	*Bushels*	*Bushels*
Mar. 20 to Apr. 5	17	181	30	17	13
Apr. 6 to 30	56	670	37	21	16
May 1 to 10	67	729	35	19	16
May 11 to 31	77	935	31	17	14
June 1 to 28	28	350	38	22	16

Estimates of corn yields after vetch and winter peas according to the date of planting are given in table 5 for five different periods of planting. After eliminating farms on which the dates of planting differed, following legumes and not following legumes, 245 farms remained.

The increased yield of corn due to the use of winter legumes averaged 16 bushels per acre for plantings from April 6 to May 10 and this was a larger increase than for earlier or later plantings except that for the latest planting dates—June 1 to 28—it was also 16 bushels increase per acre. On 123 acres on 8 farms of this group the yield of corn averaged 52 bushels per acre after the winter legumes and 36

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bushels per acre without the legumes. Such high yields on so many acres can be explained only on the assumption of a superior quality of land; it was a mere accident that these farms fell into the last group.

COTTON

Increase in yields of cotton grown after winter legumes is smaller on a percentage basis than the increase of corn, but compares well in value per acre. The average increase for the total acreage studied was 100 pounds of lint cotton per acre, or one fifth of a bale (table 3). This increase per acre is more than the entire production per acre of much land as it is now being farmed.

Crimson clover gave the largest increase in yield of cotton but its use is restricted to the piedmont soils. Expressed as a percentage of the yield of cotton without winter legumes, the yield after crimson clover was increased 40 percent; after vetch, 39 percent; after bur

FIGURE 4.—Austrian winter peas on a farm near Madison, Ga., being plowed down with a tractor.

clover, 33 percent; and after winter peas, 31 percent. The expenses in connection with winter peas were smaller than those connected with vetch and the net profit was greater. Winter peas are grown mostly in the southern part of the area, in the Coastal Plain, where there was less expense in preparing the land for planting (fig. 4).

Yields of cotton for 5 consecutive years, after legumes and without them, are shown in table 4 and figure 5. The relation between the bars representing yield of cotton grown after winter legumes and that grown without them is not so uniform as for corn (fig. 1). This lack of uniform relationship occurs for 1925 and 1926 and may be explained largely by the smaller number of estimates for these years and by abnormal yields on some of the farms. For the years 1927, 1928, and 1929, the bars (fig. 5) have a rather uniform correlation, indicating that the seasons affected the yield of cotton grown after winter legumes about the same as they did the cotton grown without them.

Fourteen farmers gave estimates of the average yield of cotton grown after winter legumes for periods of 3 to 5 years. The average of these 14 estimates was 404 pounds of lint cotton per acre when

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grown after winter legumes and 260 pounds when grown without them, an increase of 144 pounds, or 55 percent.

RESIDUAL EFFECT OF USING WINTER LEGUMES

In the clover and alfalfa area it has been the experience of farmers that the effect of plowing down these crops or even plowing under the stubble and roots, is to increase the yields of corn, potatoes, etc., above the yield obtained without legumes and that this effect continues in diminishing degree for 2 or 3 years or even longer.

At the Central Experimental Farms, Ottawa, Canada, red clover was grown on plots in 1900. The yields of corn on the check plots the first year afterward (1901), and of oats the second year afterward (1902), were greatly increased. The third year afterward (1903),

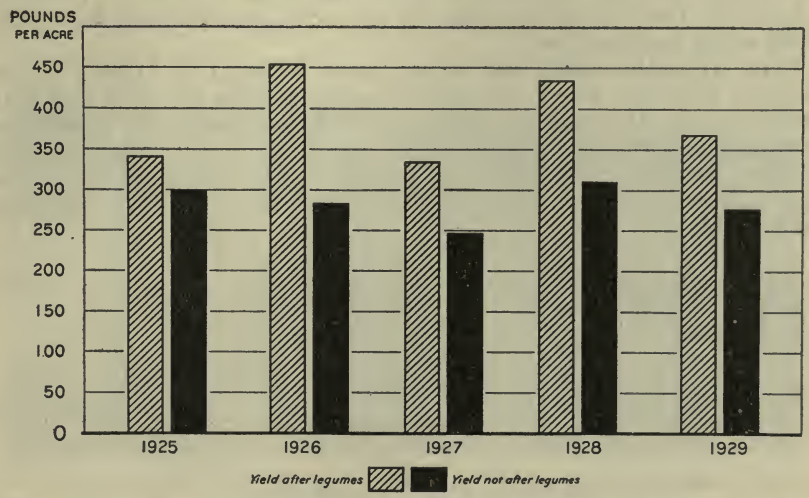

FIGURE 5.—YIELD OF LINT COTTON GROWN AFTER WINTER LEGUMES AND WITHOUT WINTER LEGUMES.

The increase in the yield of cotton resulting from fertilizing with winter legumes was very small in 1925 and very large in 1926, due to an abnormally low yield on 1 farm out of 3 in 1925 and to abnormally high yields on 3 farms out of 8 in 1926. For later years a larger number of farms were averaged and the increases in yield were more regular.

the yield of potatoes was increased from 175 bushels per acre to 195 bushels, the yield of carrots from 20.32 tons per acre to 31.48 tons, and the yield of sugar beets from 8.6 tons to 22.3 tons per acre.

At the Alabama Canebrake Station, plots of crimson clover and bur clover were turned under in 1907 and cotton was planted on these plots in 1907, 1908, and 1909, but no clover was grown after 1907. An adjacent plot was fertilized annually with 200 pounds cottonseed meal per acre and 200 pounds of superphosphate per acre; a check plot received no treatment. The total yield of seed cotton per acre in 3 years was 2,356 pounds on the check plot; 2,646 pounds on the fertilized plot; 2,842 pounds on the crimson-clover plot; and 2,856 pounds on the bur-clover plot, the clover plots having received no fertilizer.

At the Mississippi (Delta) experiment station, unpublished data show that the yield of cotton has been increased by use of various

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winter legumes to the extent of 200 to 400 pounds of seed cotton per acre the second year after the legume was plowed under, these results being an average of trials over 4 years.

Further evidence of the residual effect of winter legumes is found in the use of Monantha vetch at the Alabama experiment station in 1925, 1926, and 1927, in relation to the yield of corn in 1928. Data relating to these experiments will be found in table 6. Corn followed vetch in each of the first 3 years and its yield was increased by the vetch. In early January of the fourth year (1928) the vetch was frozen and the residual effect in 1928, therefore, came from what remained of the influence of vetch over and above what the corn had used during the first 3 years. How long this effect would have lasted if no more winter legumes had been plowed under is not known. The experiment was not designed to show the residual effect of vetch on subsequent crop yields but because the vetch accidentally froze that effect could be measured.

Even when the vetch was turned under as early as March 25 (for the first 3 years), when the average green weight per acre was only 4,629 pounds, the residual effect in 1928 was nearly 10 bushels of corn per acre over the no-nitrate plot, and 4.3 bushels per acre over that produced by 100 pounds of nitrate of soda per acre applied in 1928 and whatever nitrate may have been left over from previous years (table 6).

TABLE 6.—*Residual effect of vetch turned under in 1925, 1926, and 1927 on the corn yield of 1928 at the Alabama Agricultural Experiment Station* [1]

Plot No.	Date of—		Nitrate of soda per acre	Average weight of green vetch per acre for 1925, 1926, and 1927 [2]	Yield of corn per acre in 1928	Increase per acre over yield without nitrate of soda
	Turning vetch	Planting corn				
			Pounds	*Pounds*	*Bushels*	*Bushels*
1 and 5		Apr. 5			6.1	
2		do	100		11.7	5.6
3		do	200		22.6	16.5
4	Mar. 25	do		4,629	16.0	9.9
5 and 9		do			9.4	
6		Apr. 20	200		22.0	12.6
7		do	300		26.3	16.9
8	Apr. 5	do		8,147	28.9	19.5
9 and 13		Apr. 5			12.9	
10		May 1	200		25.0	12.1
11		do	400		36.8	23.9
12	Apr. 15	do		12,014	34.6	21.7

[1] BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. EXPERIMENTS WITH LEGUMES. Ala. Agr. Expt. Sta. Bul. 232, table 6. 1930.

[2] Corn was planted after vetch in each of these years, but in January 1928, the Monantha vetch on plots 4, 8, and 12 was killed; hence there was no vetch to turn under in 1928, but nitrate of soda was applied as in previous years. All plots were fertilized alike with superphosphate and potash.

Better residual effects were obtained when the vetch was turned under later, the quantity of nitrogen and organic matter being greater then. For the second date of turning the vetch (Apr. 5) and for the corn planting (Apr. 20) the residual effect was greater than from the use of 300 pounds of nitrate of soda per acre; the yield was 28.9 bushels compared with 26.3 bushels.

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A clear instance of the residual effect of winter peas on oats is shown in figure 6. Cotton had preceded the oats on the entire field; winter peas had preceded the cotton on one side of the field but not on the other. Oats from the two parts of the field were not thrashed separately, but the owner estimated the yields at 10 bushels and 30 bushels per acre and the authors estimated them at 10 and 25 bushels, respectively.

COST OF USING WINTER LEGUMES

Several cost items in the growing of crops are the same regardless of whether the crops follow winter legumes. The work of breaking the land is the same except in cases of very heavy legume growth. The work of cultivating the crop is the same in either case. The labor of

FIGURE 6.—Oats on a farm near Lafayette, Ala. Cotton preceded oats on the entire field. Winter peas preceded cotton on the right but not on the left.

harvesting the subsequent crop is different only to the extent of harvesting the increased yield.

The first part of table 7 gives figures on the cost of starting winter legumes in the fall. The second part of the table gives figures that show the cost of growing and harvesting the increase in yield of the subsequent crop, due to the use of winter legumes. All of the costs in the fall, in starting the legume, are charged to the subsequent crop. In the following year, the additional cost on the cotton or corn crop because of the winter legume, consists of the extra work of plowing down the legume as compared with plowing the bare soil; the extra labor of harvesting and hauling the increased yield; and, in the case of cotton, the extra cost of ginning and wrapping the increased yield. These costs are designated as costs in starting the legume and "extra costs" on the subsequent crop.

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TABLE 7.—*Extra cost per acre to produce corn and cotton after winter legumes*[1]

COST FOR STARTING LEGUMES AT HIGH PRICES[2]

Item	For corn			For cotton		
	Cash cost	Non-cash cost	Total cost	Cash cost	Non-cash cost	Total cost
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Seed and inoculation	2.96		2.96	3.12		3.12
Man labor		0.67	.67		0.60	60
Horse labor		.80	.80		.67	.67
Implement and machinery charge		.27	.27		.18	.18
Fertilizer	.81		.81	.50		.50
Total	3.77	1.74	5.51	3.62	1.45	5.07
EXTRA COST ON SUBSEQUENT CROP						
Man labor gathering extra yield		.35	.35	.45	[3] 2.50	2.95
Ginning and wrapping extra yield				1.04		1.04
Horse labor gathering extra corn		.35	.35			
Wagon charge gathering extra corn		.05	.05			
Hauling extra cotton to gin					.60	.60
Extra work plowing down legume		.25	.25		.30	.30
Total		1.00	1.00	1.49	3.40	4.89
Grand total	3.77	2.74	6.51	5.11	4.85	9.96
Credit for fertilizer	.90		.90	1.31		1.31
Credit for labor applying fertilizer		.07	.07		.04	.04
Total credit	.90	.07	.97	1.31	.04	1.35
Net cost at high prices[4]	2.87	2.67	5.54	3.80	4.81	8.61
Net cost at low prices[4]	1.88	1.48	3.36	2.39	2.52	4.91

[1] 4,145 acres of corn and 1,877 acres of cotton were studied.
[2] Figures in last line of table show net cost at low prices.
[3] This amount is about 85 percent of the total of $2.95 on the assumption that 85 percent of the cotton was picked by the families and only 15 percent was picked by hired labor.
[4] Prices used in calculating costs: High prices: Man and horse labor, 15 cents an hour; legume seed, $3 an acre; ginning and wrapping $5 a bale; fertilizers, prices of 1927, 1928, 1929. Low prices: Man and horse labor, 7½ cents an hour; legume seed $2 an acre; ginning and wrapping, $3.50 a bale; fertilizers, 85 percent of prices of 1927, 1928, and 1929.

As computed in this study, cash costs for starting the winter legume and the extra costs for growing and harvesting the additional yields of cotton and corn resulting from the use of the legume, are for legume seed, inoculation, fertilizer, cotton ginning and wrapping, and the part of the labor that is hired. The noncash costs are for the labor that was not paid for in cash, mule work, and implement and machinery charges. Labor on the small farms is usually done by the farmer and members of his family; labor on the plantations is done by the share cropper and family. In the latter case there was probably a little labor for which cash was paid that was not so classified in making the computations, but it is a small item and is covered in the total cost. It is estimated that the farm operators and their families, plus the share croppers and their families, picked 85 percent of the cotton crop, hence only 15 percent of the picking charge is a cash cost. A small part of the implement and machinery charge for operating the farm is cash but the implements were used chiefly on other enterprises and the cash part of such cost for winter legumes is negligible.

Costs for starting winter legumes in the fall amounted to $5.51 per acre of corn and $5.07 per acre of cotton. In the following season, the

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extra cost of growing and harvesting the corn crop was only $1 per acre whereas for cotton it was $4.89 per acre, nearly all of which was for picking, ginning, wrapping, and hauling the increase in yield due to the use of the legumes.

The total extra cost was $6.51 per acre of corn and $9.96 per acre of cotton. Of these totals $3.77 was the cash cost for corn and $5.11 the cash cost for cotton. But certain expenses for fertilizer must be deducted from the total costs to obtain the net cost of using winter legumes, because less fertilizer was used on the corn and cotton that followed the legumes than was used on these crops when grown without winter legumes. These deductions are shown in the lower part of table 7 and are referred to as "credits." The average fertilizer application per acre to corn following legumes was 10 pounds of nitrate of soda and 49 pounds of other fertilizer, whereas on corn not following legumes it was 36 pounds of nitrate of soda and 66 pounds of other fertilizer. On cotton following legumes the average application per acre was 43 pounds of nitrate of soda and 419 pounds of other fertilizer; on cotton not following legumes it was 85 pounds of nitrate of soda and 427 pounds of other fertilizer.

The cost of the extra fertilizer for the corn not following legumes, plus the labor of applying it, was 97 cents an acre; for cotton it was $1.35 an acre (table 7). Deducting these items from the total extra cost of the crops after the legumes, leaves a net extra cost of $5.54 an acre for corn and $8.61 an acre for cotton in comparison with cost of the same crops not following legumes, these figures being according to high prices. (See footnote 4, table 7.)

There is not much opportunity to reduce these costs. It would be convenient and helpful if farmers could raise their own legume seed but that does not seem practicable in the case of vetch and winter peas which are the most popular winter legumes. The extra cost of plowing under the legumes in certain cases can be reduced or eliminated by the proper implements and by good management, but it is a small cost on the average because it has been eliminated already in a majority of cases.

PROFITS FROM USE OF WINTER LEGUMES

CORN

That the use of winter legumes as fertilizer increases the yield of the crops that follow in the rotation is well known, but the amount of the increase, the cost in cash outlay, the labor of men and teams involved, and the degree of wear on implements are items regarding which there is limited information. The value of the increase in yield minus the expenses for legume seed, fertilizer, labor, etc. (table 7), is the profit or net gain from the use of winter legumes as fertilizers.

The increase in yield of corn averaged about 14 bushels per acre for all farms and was valued at $1 a bushel, at high prices, and at 50 cents a bushel, at low prices (table 8). These are much above Corn Belt prices for the reason that the South produces a deficiency of corn whereas the Corn Belt produces a surplus. To the value of the increase in yield of corn is added an average pasture value of 63 cents an acre and 30 cents an acre at high and low prices, respectively. This added amount is small because the acreage pastured was small, and the whole acreage was averaged to obtain the result.

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TABLE 8.—*Average increase in yield, cost, and net gain per acre from the use of winter legumes for corn and cotton*

Item	Corn [1]		Cotton [2]	
	At high prices	At low prices	At high prices	At low prices
	Dollars	*Dollars*	*Dollars*	*Dollars*
Value of increase in yield [3]	14.10	7.05	18.00	7.00
Value of legume pasture and hay	.63	.30	.30	.15
Total	14.73	7.35	18.30	7.15
Net cash cost [4]	2.87	1.88	3.80	2.39
Net noncash cost [4]	2.67	1.48	4.81	2.52
Total net cost	5.54	3.36	8.61	4.91
Net gain, all costs considered	9.19	3.99	9.69	2.24
Net gain, only cash costs considered	11.86	5.47	14.50	4.76

[1] 4,145 acres with increase in yield per acre of 14.1 bushels.
[2] 1,877 acres with increase in yield per acre of 100 pounds lint.
[3] Corn is valued at $1 a bushel, high-prices and 50 cents a bushel, low-prices. Cotton is valued at $90 a bale, cottonseed included, at high-prices, which is approximately 15 cents per pound of lint; and $30 per ton of seed and $35 a bale, at low-prices, which is approximately 6 cents per pound of lint and $10 per ton of seed.
[4] Taken from the last 2 lines of table 7.

On the basis of high prices the net cost of $5.54 an acre deducted from the extra value of $14.73 an acre leaves a net gain of $9.19 an acre, but when cash costs only are considered the net gain is $11.86 per acre.

On the basis of low prices the net cost of $3.36 an acre, deducted from the extra value of $7.35 an acre, leaves a net gain of $3.99 an acre, but when cash cost ($1.88 an acre) only are considered, the net gain is $5.47 an acre.

On the basis of low prices for corn, labor, and materials the net gain is reduced but is still substantial. Therefore, at any probable price of corn for a period of years, a safe average profit from the use of winter legumes is likely.

The meaning of this to southern agriculture is evident. Low yields of corn will give way to medium and high yields as farmers use winter legumes. It may be that no increase of acreage will be necessary to make the South self supporting in regard to corn if winter legumes are generally used as fertilizers.

It may be asked whether the increased yields are greater in the lower Southeast than in the upper Southeast. To determine this the latitude of 33°, which is that of middle Georgia and Alabama, was made the dividing line between the upper and the lower South, in carrying on this study.

The results of this inquiry are embodied in table 9 and are confined to the effects of growing vetch and winter peas, because these legumes were found both north and south of this latitude, whereas crimson clover and bur clover were found only north of the line. The figures show somewhat better results south of the line than north of it. Whether this difference is related to the kind of soil or to the date of plowing under the legume and planting the subsequent crop is uncertain. South of the line, in the Coastal Plain, the soils are mostly sandy, whereas north of it they are mostly clay and silt loam. The net gain per acre south of the line was $2.33 greater for corn and $3.26 greater for cotton than the net gain north of the line, on the basis of high prices.

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TABLE 9.—*Average increase yield and net gain per acre from the use of vetch and winter peas for corn and cotton, north and south of latitude 33°*

Item	Corn		Cotton	
	North of 33°	South of 33°	North of 33°	South of 33°
Acres ... number	1,301	2,660	725	1,015
Increase in yield per acre ... bushels	12.6	14.7		
Increase in yield per acre ... pounds of lint			91	101
Net gain per acre, all costs considered[1] ... dollars	7.34	9.67	7.32	10.58
Difference in favor of crops south of latitude 33° ... do		2.33		3.26

[1] High prices used for this table. See notes, tables 7 and 8.

COTTON

The method of calculating the net gain of cotton following winter legumes is the same as that for corn. Details of the expenses are found in table 7 and are summarized in table 8 for the purpose of calculating the net gain.

For this purpose cotton is valued at $90 a bale, cottonseed included, at high prices, and at $35 a bale at low prices. The increased yield of 100 pounds of lint cotton per acre, plus the cottonseed, was worth, at high prices, $18. To this sum 30 cents an acre was added as the value of the legumes eaten by livestock. Thus, with an increased value of $18.30 an acre and an increased cost of $8.61 per acre, there is left $9.69 as the net gain, all costs considered; or $14.50 an acre with cash costs only considered.

At $35 per 500-pound bale of cotton, including seed, the net gain per acre dropped to $2.24 an acre, all costs considered, and to $4.76 an acre with cash costs only considered.

On the basis of high prices (table 8) the net gain per acre is a little greater for cotton than for corn but for low prices the monetary advantage rests with corn.

The yield of lint cotton was 10 pounds per acre greater south of 33° than north of 33°; on the basis of high prices the net gain was $3.26 per acre greater south of 33° than north of it. The monetary gain is due partly to increased yield and partly to decreased cost.

VARIATIONS IN PROFIT

It is not expected that plowing under winter legumes will always increase yields. No practice, new or old, brings perfect results every time. Table 10 shows that on 62 acres of corn grown after winter legumes, the yield was 7.3 bushels per acre less than of corn grown not after legumes, and on 357 acres there was no increase in yield due to the use of winter legumes. These acreages, taken together, constitute only 10 percent of the total acreage of corn included in this study. On the other 90 percent there was a profit or net gain ranging from $1.54 an acre on the third group of farms shown in table 10 to $29.52 on the last group, based on high prices. At low prices the net gain ranged from 50 cents an acre on the third group of farms to $13.41 on the last group, but on the first two groups there was a monetary loss (fig. 7).

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TABLE 10.—*Average yield and net gain per acre of corn grown after winter legumes, by specified increases in yield, based on high and low prices*

Increase in yield (bushels)	Acreage studied	Yield per acre			High prices [1]			Low prices [2]		
		After legumes	Not after legumes	Increase	Value of increase per acre	Total extra cost per acre	Net gain per acre	Value of increase per acre	Total extra cost per acre	Net gain per acre
	Acres	*Bushels*	*Bushels*	*Bushels*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Decreases	62	15.1	22.4	[3] −7.3	[3] −7.30	3.40	[3] −10.70	[3] −3.62	2.30	[3] −5.92
No increase	357	19.2	19.2	0	[4] .75	3.65	[3] −2.90	.38	2.05	[3] −1.67
1 to 5	408	21.8	17.0	4.8	5.55	4.01	1.54	2.77	2.27	.50
5½ to 10	908	28.9	19.8	9.1	9.41	5.26	4.15	4.72	3.05	1.67
10½ to 15	1,071	35.0	20.3	14.7	15.21	6.27	8.94	7.64	3.98	3.66
15½ to 20	559	38.3	19.2	19.1	19.22	5.96	13.26	9.43	3.68	5.75
20½ to 25	427	46.4	22.7	23.7	24.02	5.08	18.94	11.98	2.92	9.06
25½ to 30	132	54.2	25.3	28.9	31.63	6.04	25.59	15.82	3.54	12.28
Over 30	221	56.8	18.6	38.2	38.77	9.25	29.52	19.38	5.97	13.41
Total and weighted average	4,145	34.1	20.0	14.1	14.73	5.54	9.19	7.35	3.36	3.99

[1] Prices used in calculating costs and net gains. High prices: Corn, $1 a bushel; man labor and horse work 15 cents an hour; legume seed, $3 an acre; fertilizers, prices of 1927, 1928, and 1929.
[2] Prices used in calculating costs and net gains. Low prices: Corn, $0.50 a bushel; man labor and horse work 7½ cents an hour; legume seed, $2 an acre; fertilizers, 85 percent of prices of 1927, 1928, and 1929.
[3] Decrease.
[4] Credits from grazing and from legume hay harvested account for a slight gain in value per acre even when there was no increase in the yield of corn.

Causes of these variations in yield are numerous. A comparable table could be made on the results obtained on crops from the use of

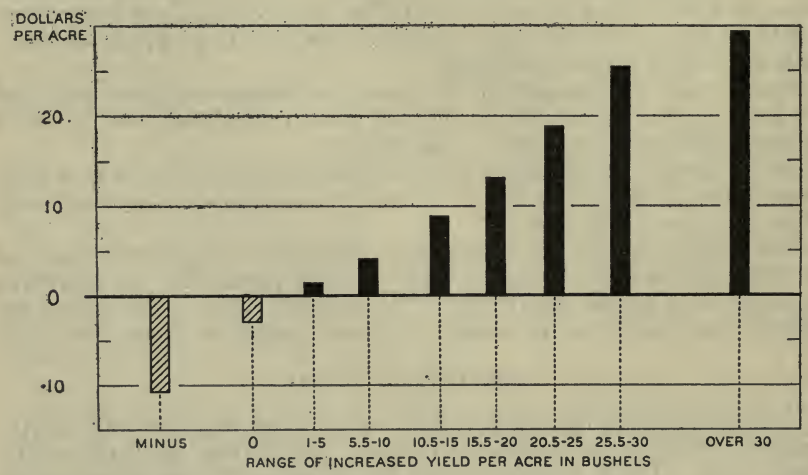

FIGURE 7.—NET MONEY GAIN PER ACRE ON CORN GROWN AFTER WINTER LEGUMES ACCORDING TO THE INCREASED YIELD.

With corn worth 50 cents to $1 a bushel it takes an increased yield of about 5 bushels an acre to pay the cost of the winter legume.

fertilizers. Differences are found in soils, methods of preparation and planting, time of preparation and planting, seasons, and extent of damage by insects and diseases.

The interviewed farmers said more about damage from insects than about damage from other causes. Concerning insects that damaged the stand of young corn following winter legumes much was said about "bud worms", but since this name is applied to the larvae of several insects it was not easy to identify the species meant.

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It is known, however, that one of the insects that often does serious damage of this kind is the southern corn rootworm (*Diabrotica 12-punctata Fab.*). In the spring of 1929 the writers inspected plots of corn following winter legumes on the grounds of the Alabama Agricultural Experiment Station and saw stands of corn that had been made very imperfect by this insect. This use of these plots constituted an experiment to determine the extent of infestation of this insect according to dates of plowing under the legume and dates of planting corn thereafter. According to these experiments the technic of outwitting the southern corn rootworm appears to consist of (1) plowing the land on which winter legumes are growing somewhat later than March—say April 15 in the latitude of Auburn, Ala.; (2) covering the legume completely with the plow, followed by the disk harrow; and (3) waiting about 3 weeks before planting corn, although 2 weeks may be long enough in many cases. In late seasons the turning and planting date should be somewhat later.[2]

Another insect that has damaged vetch, the crops planted thereafter, and the crops in the vicinity, is the so-called "vetch worm", which is the same as the corn ear worm (*Heliothis obsoleta*), and is sometimes called the army worm. Several farmers referred to these "worms" as having damaged their crops. The writers saw one field of vetch that had been completely defoliated by the corn ear worm which then spread to an adjacent field of young cotton and injured the stand. At another place the writers saw corn ear worms in a peach orchard in which vetch was the winter cover crop, eating the vetch foliage, and even eating holes in young peaches on the trees.

This sounds more alarming than it really is. Vetch is large enough to use as a fertilizer before the corn ear worm hatches, hence a simple method of control when the crop is to be used as a fertilizer is to plow it under before the "worms" appear. Close daily examination of the vetch after it reaches the early hay stage of growth would reveal the tiny worms, if present, before they are large enough to do serious damage. The corn ear worm does not injure the vetch every year; it depends largely upon the weather. It is most likely to appear after a period of cool, moist weather.[3]

The writers heard no complaint about injury to winter peas and to Monantha vetch by the corn ear worm. In the peach orchard referred to, scattering plants of winter peas were mixed with the vetch but no injury was done to them.

Concerning variations in the increase in yield of cotton following winter legumes there were 55 acres out of a total of 1,877 acres on which the yield after winter legumes was 122 pounds of lint per acre compared with 298 pounds per acre not after them, or a decrease of 176 pounds per acre; and on 284 additional acres there was neither increase nor decrease. There was, of course, a net money loss from the use of winter legumes on these two groups of farms according to high prices as shown in table 11, and on three groups according to low prices (table 11 and fig. 8).

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[2] For further information about the southern corn rootworm, see the following publications:
LUGINBILL, P. THE SOUTHERN CORN ROOTWORM AND FARM PRACTICES TO CONTROL IT. U.S.Dept.Agr. Farmers' Bul. 950, 12 p., illus. 1918.
ARANT, F. S. BIOLOGY AND CONTROL OF THE SOUTHERN CORN ROOTWORM. Ala. Agr. Expt. Sta. Bul. 230, 46 p., illus. 1929.

[3] Further information about "vetch worms" will be found in the following publications: LUGINBILL, P. CORN EARWORM AS AN ENEMY OF VETCH. U.S.Dept.Agr. Farmers' Bul. 1206, 19 p., illus. 1921.

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TABLE 11.—*Average yield and net gain per acre of cotton grown after winter legumes, by specified increases in yield, based on high and low prices*

Increase in yield (pounds of lint)	Acreage studied	Yield of lint per acre			High prices [1]			Low prices [3]		
		After legumes	Not after legumes	Increase	Value of increase per acre [2]	Total extra cost per acre	Net gain per acre	Value of increase per acre [2]	Total extra cost per acre	Net gain per acre
	Acres	*Pounds*	*Pounds*	*Pounds*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Decreases	55	122	298	[4]—176	[4]—25.62	[4]—4.77	[4]—20.85	[4]—9.29	[4]—2.55	[4]—6.74
No increase	284	306	306	0	.32	3.19	[4]—2.87	.16	1.69	[4]—1.53
1 to 50	195	315	282	33	6.50	5.68	.82	2.59	2.95	[4]—.36
51 to 100	487	377	291	86	15.85	6.77	9.08	5.97	3.79	2.18
101 to 150	470	405	270	135	24.35	11.61	12.74	9.47	6.57	2.90
151 to 200	210	492	306	186	33.46	13.19	20.27	13.04	8.13	4.91
201 to 250	121	473	240	233	41.85	14.58	27.27	16.26	8.19	8.07
Over 250	55	593	272	321	57.70	20.65	37.05	22.44	12.22	10.22
Total and weighted average	1,877	381	281	100	18.30	8.61	9.69	7.15	4.91	2.24

[1] Prices used in calculating cost and net gain. High prices: Cotton, $90 a bale including cottonseed; man labor and horse work, 15 cents an hour; legume seed, $3 an acre; ginning and wrapping, $5 a bale; fertilizers, prices of 1927, 1928, and 1929.
[2] Including credit from legume, hay, and pasture.
[3] Prices used in calculating cost and net gain. Low prices: Cotton, $35 a bale including cottonseed; man labor and horse work, 7½ cents an hour; legume seed, $2 an acre; ginning and wrapping, $3.50 a bale; fertilizers, 85 percent of prices of 1927, 1928, and 1929.
[4] Decrease.

Serious damage was frequently ascribed to the boll weevil, particularly where the crop was planted late, and in a few cases complaint

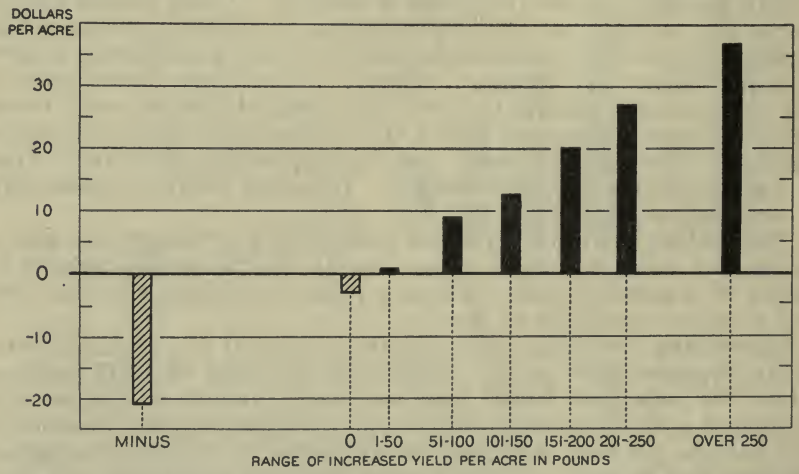

FIGURE 8.—NET MONEY GAIN PER ACRE ON COTTON AFTER WINTER LEGUMES ACCORDING TO THE INCREASED YIELD.

With cotton selling at 6 to 15 cents per pound, the yield of lint must be increased 30 to 50 pounds per acre, using winter legumes as fertilizers, before any net gain can be obtained.

was made of the ravages of the cotton flea hopper (*Psallus seriatus*). It sometimes happened that the cotton following the winter legume was planted considerably later than that which did not follow the legume and in these cases the damage from boll weevil was worse on the former crop than on the latter. Cotton flea-hopper damage was greater on the crop following the winter legume than on the check

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crop. In one case the county agent, who had been in close touch with the farmer, said that the greater injury to the cotton following the winter legume was due to the dense shade of the crop caused by the much larger growth—that he had had the same experience with fertilized cotton versus unfertilized cotton.

The vegetative growth of cotton, corn, and other crops grown after winter legumes is excellent, but if the stand is not so good as on the check crop, or if damage caused by insects or diseases is great, there may be no gain in yield and may even be a loss. In the use of winter legumes for fertilizing, the first consideration is to get a good stand and growth of the legume, the second is to get a stand of the crop following the legume, and the third is to prevent insects and diseases from causing damage.

GRAZING VALUE OF WINTER LEGUMES

The number of the men interviewed who could furnish data on the grazing value of winter legumes was so small that it is hardly worth while to give averages. Those who had had long experience were positive in their assertions that, for grazing alone, the legumes pay. Usually oats or rye are planted with the winter legume when grazing is desired. Winter peas can be grazed earlier than hairy vetch but do not recover so well after grazing. A few farmers stated that their cattle and mules would not eat winter peas, but one farmer stated that cattle prefer winter peas to oats. The tips of winter peas are tender and well-flavored enough to make greens for the table.

An outstanding instance of the value of winter peas for grazing was furnished by the experience of a farmer in southern Alabama who grazed 30 hogs on 5 acres of this legume from March 1 to May 1, during which time they gained 75 pounds apiece. He estimated that 125 bushels of corn were fed to them during this period. The hogs sold for 9.4 cents a pound on foot and the corn was valued at $1 a bushel. It was figured that the net gain on the hogs, over and above the value of the corn fed to them, was about $17 per acre of winter peas.

Winter legumes and winter grains combined may be effectively used for grazing. Pasturing makes it possible to get returns a few months after planting and to keep the winter legumes from becoming too large to plow under easily.

REASONS WHY WINTER LEGUMES ARE SPARINGLY USED

With the good showing made by winter legumes in regard to both corn and cotton it may be asked why more farmers do not plant them. There are two chief reasons: (1) It takes time to get a new practice or a new crop started. It took time to make alfalfa and soybeans important crops. A few farmers in central New York raised alfalfa 100 years, more or less, under the name of lucerne before the crop spread eastward from California, and even after it was much talked about and written about, farmers were slow to plant it. (2) The expense of the seed, which has to be planted in the fall with the knowledge that the returns in increased yields of cotton and corn cannot be realized in less than a year, is discouraging to men who have little money.

Minor deterrents are conflict of work in cotton-picking time in getting the legume planted, difficulty of turning under the legume in

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the spring with the small plows and teams that are commonly used, and difficulty in getting a stand of the following crop in first attempts. All these deterrents, except that of spending money for the seed a year before returns come in, can be overcome as farmers get more experience; and as country bankers are becoming acquainted with the benefits of winter legumes, they are more ready to lend money for such production.

PREPARING LAND FOR WINTER LEGUMES AND PLANTING THEM

PREPARING LAND

In the planting of vetch there were 26 cases out of 264 in which the land was first plowed (flat broken) and then harrowed; then the seed was planted. In 24 cases the land was not plowed but was harrowed with a disk harrow, and in 214 cases vetch was seeded in the middle between row crops.

Out of 193 instances of winter peas the land was plowed in 29 cases, disked without plowing in 19 cases, and seeded in row crops in 145 cases. With a 1-horse drill that runs between the cotton rows, the winter legumes can be planted without additional preparation of the land and, if a drill is not available, the seed may be broadcast and then covered with a 1-horse or 2-horse cultivator or with a 1-horse plow.

The indicated variations in the methods used in preparing the seed bed for winter legumes are largely due to the condition of the land to be prepared. Land in sod or grain stubble, or with considerable vegetative growth, requires plowing and harrowing for a suitable seed bed. Cowpea or soybean stubble frequently can be put in shape without plowing, the disk being used instead. Land that has been in row crops, like corn, cotton, peanuts, and tobacco, can be satisfactorily seeded to legumes without any preparation if the crops were cultivated well and were free from weeds.

SEED AND FERTILIZER

The quantity of vetch seed planted on 3,211 acres was 73,908 pounds or 23 pounds per acre. The smallest quantity per acre was 10 pounds and the highest 35. The average price paid was slightly more than 13 cents a pound, but the price ranged from 9 to 20 cents.

The winter peas planted on 2,490 acres amounted to 76,936 pounds, or an average of about 31 pounds per acre with a range of from 15 to 60 pounds. The price range was from 7½ to 15 cents and averaged nearly 9½ cents.

Most of the crimson-clover seed was raised at home and sowed in the chaff at the rate of 30 pounds per acre. This would be equal to about 20 pounds of clean seed which is a greater quantity than would be used if the seed had to be bought.

On the poorer soils it seems necessary to fertilize winter legumes in order to grow them successfully. In 179 cases out of 500, fertilizer was used at an average rate of 328 pounds per acre; in 321 cases it was not used at all. Superphosphate was the most common fertilizer and was used at the rate of nearly 300 pounds per acre; in central Alabama, which is near the supply of basic slag, farmers used from 400 to 600 pounds of the latter per acre which cost them $10 to $12 per ton.

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INOCULATION

The first plantings of a winter legume are nearly always inoculated, either with a pure culture or with soil from an old field, or with both. Using both appears to be more effective in a majority of cases than depending on pure cultures alone. The few farmers who do not inoculate their first plantings do not get successful results. For later plantings on the same land, some farmers inoculate and some do not.

The method of inoculating with soil is, usually, to obtain some soil from the old field, dry it, and sift it to remove lumps and stones; then drill it with a fertilizer distributor at the rate of 50 or more pounds per acre. Sometimes the legume seed and the soil are drilled together, and if basic slag is used it is not uncommon to mix soil, seed, inoculation, and slag, and drill them together. Superphosphate is rarely, if ever, mixed in this way for fear of killing the inoculation.

SOWING

The method of broadcasting vetch and covering with scratcher, harrow, cultivator, or plow accounts for 140 cases out of 264; in the other 124 cases the seed was drilled in. In planting winter peas the broadcast method was used in 137 cases and the drill method in 56 cases. Drills are not numerous enough in this part of the country. Fertilizer distributors were used as drills on a number of farms and were classed as drills. In central Alabama many farmers mix basic slag and seed together and put it out with a fertilizer distributor by going twice to the row. In the case of 3-row drills, as the middle hole is usually closed, all the seed goes down the outside drills. Legumes in the middle drill row, if there is one, do not grow well because the middle is low and often wet and because there is no left-over fertilizer in the middles whereas there is unused fertilizer at the base of the old cotton stalks, close to the legume drills or rows.

One danger in drilling vetch seed on sandy land is that the young plants will be "sanded" or covered with sand. When vetch first comes up it flattens out on the ground; then with a rain, the water runs down the little drill furrows, washing out here and filling in there. If the vetch were upright when small, sanding would not be so likely to happen. The precaution against sanding is to fit a smoothing board or chain harrow on the rear of the drill so that no furrows will be left. The method of covering broadcast seed with a small plow is preferred to covering with a scratcher or harrow.

Drilling, properly done, gives better results than does broadcasting. Drilled plantings do not heave so badly during freezing and thawing weather. The 3-year average yield per acre of winter peas, green weight, at the Alabama experiment station, was 5,186 pounds for the broadcast plantings and 6,906 pounds for the drilled plantings of September 30. Similar results were obtained with hairy vetch and Monantha vetch of the same date of planting and for later dates of planting.[4]

The range of dates for sowing vetch and winter peas both north and south of latitude 33° is from about October 1 to the middle of November, but the averages for both vetch and winter peas and for farms both north and south of 33° fall in October (table 12). The

[4] Bailey, R. Y., Williamson, J. T., and Duggar, J. F. Op. cit., table 12.

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date of sowing crimson clover is earlier—usually in September. Bur clover is sowed anywhere from the middle of July to the middle of October.

TABLE 12.—*Average dates of sowing vetch and winter peas*

Legume and section	For cotton		For corn	
	Reports	Sowing dates	Reports	Sowing dates
Vetch:	*Number*		*Number*	
North of 33°	31	Oct. 15	102	Oct. 15
South of 33°	10	Oct. 27	83	Oct. 22
Winter peas:				
North of 33°	14	Oct. 20	13	Oct. 19
South of 33°	42	Oct. 17	109	Oct. 20

Figure 9 shows two fields of crimson clover near Laurens, S.C. In one the seed was sowed in cotton middles and scratched in lightly. In the other it was sowed without scratching or covering. These fields illustrate the advantage of a light covering for the seed. Occasionally good stands are obtained without covering but, as a rule, the ground needs scarifying either before or after sowing.

LABOR REQUIREMENTS

The time required in starting winter legumes depends largely upon the method of preparing the land which, in turn, depends upon the previous crop and the condition of the land. Grain-stubble land on which weeds have grown, and other land that is weedy, require plowing (flat breaking). Cowpea and soybean stubble and land on which peanuts have been grown usually can be prepared by disking or harrowing. Cotton and corn middles can be planted without preparation, provided the land is clean. Corn middles that contain cowpeas, peanuts, or other vegetation, usually cannot be seeded to winter legumes without preparation.

The average time required per acre to prepare the land and plant the legume seed with mule-drawn implements was 8.8 man hours and 12.4 mule hours for land that was plowed; 4.8 man hours and 6.1 mule hours for land that was disked and not plowed; and 3 man hours and 2.6 mule hours for land that was in tilled crops and received no further preparation previous to seeding. In the latter case, the excess of man hours over mule hours is the result of sowing some of the seed by hand (broadcast) and covering it with a mule-drawn implement.

METHODS OF TURNING VETCH AND WINTER PEAS

Both vetch and winter peas are somewhat "viney" and if the growth is large it catches on the beam standard until the plow must be stopped and the vines pulled out by hand. If plowed under at an earlier stage of growth this does not happen, but farmers frequently let the plants get large on the theory that they will be better fertilizers.

It is a mistake to let the legumes grow so large. If planted October 1 or soon thereafter and if the stand is good, there will be enough

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nitrogen in the legume for the following crop even if it is turned under 2 to 4 weeks before it reaches its maximum growth. Weights of 5,200 pounds of green vetch per acre, or 6,100 pounds of green winter pea vines per acre, contain as much nitrogen as 300 pounds of nitrate of soda.

Some farmers disk down the winter legume before plowing it, even if they have to disk twice to accomplish the job. In 45 cases of

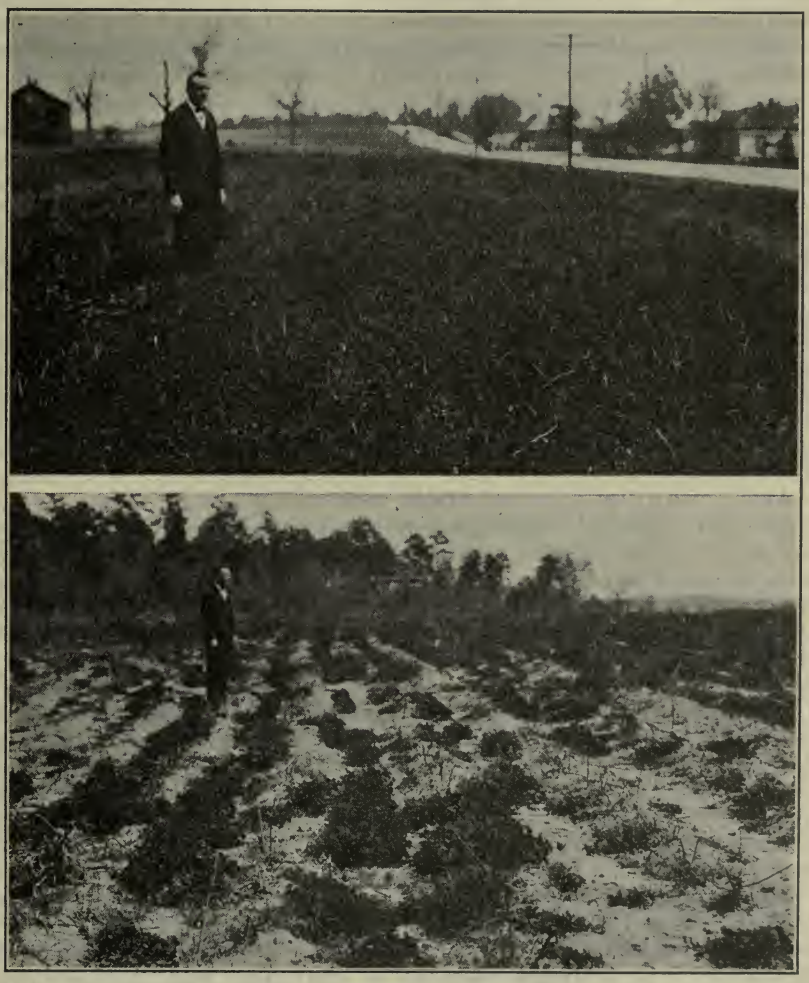

FIGURE 9.—Crimson clover on adjacent farms near Laurens, S. C. Upper: Clover seed sowed in cotton middles and scratched in. Lower: Clover seed sowed in cotton middles but not covered.

vetch out of 264, the land was disked before being plowed for the subsequent crop, but in 219 cases it was plowed without preliminary disking. In 39 cases of winter peas out of 193, the peas were disked and then plowed, but in 154 cases plowing alone was sufficient. There is no need of preliminary disking if the legume is turned in time. The extra work is an extra expense and it delays other work. Then, too, when bunches of green vetch or winter peas are pulled

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away from the bean standard and left on the ground at intervals they present a bad appearance and interfere more or less with harrowing; this could be prevented by earlier turning with good plows and accessories.

To plow under the larger growth often requires preliminary disking or the use of rolling colter and "slide", or both. The slide presses down the vetch and winter peas so that the rolling colter gets on top of them and cuts its way down through and into the soil. This cuts the furrow vetch loose from the field vetch (or peas) so that the vetch cannot catch on the beam standard and prevent the moldboard from turning and covering it. Even with colter and slide it is difficult to do a good job with a 10-inch plow. A walking plow cutting 12 to 14 inches wide does a better job, and the sulky plow cutting 14 or more inches wide does an excellent job. The disk plow is used by those who have it, and is effective for the purpose. Tractor plows, whether of the disk or moldboard type, are especially good because of their size and power. The rolling colter plow attachment is useful in turning under winter legumes, and should be in greater use. If the growth is large a slide or chain is needed on the moldboard plow to drag the plants down so they can be completely covered; a heavy chain is also useful on the disk plow. One end of the chain can be fastened to the right end of the doubletree (for right-hand plows) and allowed to drag behind, or the rear end can be attached to the beam standard with just enough slack in it so the furrow slice will barely miss it. The slide is merely a curved shank to which the rolling colter is attached.

Another way of plowing under winter legumes is known as the "hard-bed" method, considered by many an old-fashioned and careless way. Four furrows are usually thrown together, two on each side, to make a "bed." The beds are as far apart as the distance between the intended corn rows, leaving a rather deep furrow between the beds. If the rows are so wide that four furrows will not complete each bed then 1 or 2 additional furrows are thrown out or a middle burster is used to plow out the remainder at one "through". The original surface of the ground under the beds is unbroken, hence the name. The corn is planted in the bottom of the furrow immediately after "bedding" or at least within a very few days. This method is often practiced on sandy or sandy loam lands but not on clay. Heavy rains soon after the corn comes up would drown it by flooding the furrows in the clay soil, but in the sandy soils the water drains away.

A striking instance of this method was found in Edgefield County, S.C. On May 15, 1929, a field of 5 acres of vetch was disked down and then bedded with four furrows to the bed. The bedding was completed with a middle burster on that date and the corn was planted three days later in the bottom of the furrow. The corn was fertilized with 400 pounds of nitrate of soda and 100 pounds of potash manure salts per acre, and the measured yield was 105 bushels per acre (fig. 2).

A leading Georgia farmer insists that by the hard-bed method of preparing land for corn he has perpetuated vetch as a volunteer crop for six years. The land is bedded without previous disking and the vetch tops, which protrude above the beds, make seed before the middles are cultivated, and the vetch volunteers each fall. This

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method permits the planting of corn sooner after the legume is plowed under than does the method of flat breaking land, but there is some risk from injury to following crops by so-called vetch worms and by the southern corn-root worm.

DATES OF TURNING LEGUMES AND OF PLANTING THE FOLLOWING CROPS

Winter peas are turned under somewhat earlier than vetch, especially south of 33° latitude. This tends to confirm the statements of a number of farmers that winter peas are earlier than vetch and can be plowed under sooner. On the greater part of the cotton land the winter legumes are turned under in April, although the average date of turning under winter peas south of 33° was March 29 (table 13).

TABLE 13.—*Average date of turning under vetch and winter peas and of planting following crops*

Legume and section	Estimates on—		Date of—		Interval
	Turning	Planting	Turning	Planting	
FOR COTTON					
Vetch:	*Number*	*Number*			*Days*
North of 33°	39	39	Apr. 23	May 8	15
South of 33°	10	10	Apr. 20	May 1	11
Winter peas:					
North of 33°	14	14	Apr. 19	May 10	21
South of 33°	44	45	Mar. 29	Apr. 19	21
FOR CORN					
Vetch:					
North of 33°	110	113	May 4	May 19	15
South of 33°	86	86	Apr. 26	May 13	17
Winter peas:					
North of 33°	14	14	May 1	May 12	11
South of 33°	112	112	Apr. 11	Apr. 28	17

The dates of turning under winter legumes for corn are mostly in the latter half of April and the first half of May, but for farms south of 33° the winter peas were turned under during the first half of April.

Most of the cotton was planted in April and most of the corn in May, but for both cotton and corn after winter peas in the more southerly latitude, the average planting dates were in April. The interval between dates of turning under the legumes and of planting cotton and corn was usually between 2 and 3 weeks, but in a considerable number of cases the interval was less than 2 weeks.

Granting the value of winter legumes as fertilizers and the desirability of extending their use in the South, it is still a question of how large a part of the farm should be planted with them. Most of the farmers interviewed stated that 5 acres to the mule is about as much as one can plow under within the limits of time when the legumes should be turned under. This would be about 20 to 25 percent of the crop land. The acreage of winter legumes that a farmer can handle satisfactorily depends primarily upon the length of time between the date when the plowing under can begin and the date when it should end. The date of beginning to turn under the legume may be advanced in five ways:

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(1) By fertilizing the legume and getting a larger early growth; (2) by planting earlier in the fall for the same purpose; (3) by planting those varieties of winter legumes which naturally make the largest early growth; (4) by getting good stands; and (5) by turning at an earlier stage of growth than is customary. By these methods the date of beginning to turn down the legume may be advanced 15 or 20 days of which, perhaps, 10 to 14 may be utilized for field work.

The first method needs little explanation. On poor soils without fertilizer the growth is so small that it has little fertilizing value; if the legume makes a fair growth without fertilizer it makes a better growth with fertilizer and makes enough green manure early in the spring, hence can be plowed under earlier.

The second way has experimental evidence in its favor. At the Alabama experiment station the green weights of winter peas per acre for the years 1927–29 and for cuttings of March 22 were as follows: For planting of September 30, 5,909 pounds; of October 26, 4,265 pounds; of November 23, 1,545 pounds, and of December 19, 426 pounds.[5] The earliest planting, which had made nearly 6,000 pounds per acre on March 22, had as much nitrogen in it as 300 pounds of nitrate of soda. The planting of October 26 had made only 4,265 pounds on March 22 but by April 2 it had about caught up with the March 22 cutting of the earlier planting and weighed 5,948 pounds. It may be said, then, that the planting of September 30 had the equivalent of 300 pounds of nitrate of soda per acre 11 days earlier than had the planting of October 26, and on a comparable basis of fertilizing value could therefore have been plowed under 11 days earlier. In fact, the winter peas could have been plowed under with good results when the nitrogen equivalent was only 200 pounds of nitrate of soda per acre thus advancing the date of turning several more days. This, however, illustrates the fifth way of advancing the date of turning. In the same experiment, the yields of hairy vetch and Monantha vetch show similar results for different dates of planting.

The third way of advancing the date of turning depends upon the greater cool-weather growth, or early growth, of these legumes over hairy vetch. At the Alabama station the average green weight of hairy vetch for five years was 6,546 pounds on or about April 1 for the planting of October 1. For winter peas it was 9,136 pounds and for Monantha vetch it was 10,270 pounds. Monantha vetch, though making a large early growth, is not very winter-hardy even in the southern part of the area and is of less utility farther north. Hairy vetch may often equal, in early growth, these other legumes, depending on whether the winter has been warm or cold; but generally speaking it makes less early growth than these competitors.[6]

At the Georgia Agricultural College for the 2 years of 1925 and 1926 the weight of cured hay per acre on March 1 was 700 pounds of vetch and 1,650 pounds of winter peas; on March 23, 1,750 pounds of vetch and 2,300 pounds of winter peas; on April 6, 2,250 pounds of vetch and 2,300 pounds of winter peas; and on May 6, 3,900 pounds of vetch and 4,100 pounds of winter peas.[7]

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[5] BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Op. cit., table 15.
[6] BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Op. cit., table 17.
[7] TABOR, P. WINTER FORAGE AND COVER CROPS. Ga. State Col. Agr. Bul. 321, table 2, 1926.

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It may happen that whereas the green weight of winter peas is greater than that of vetch, the nitrogen content of the vetch is greater than that of the winter peas, but in most cases the winter peas contain more nitrogen on the earlier dates of plowing under, than does the vetch.

The fourth way by which the date of plowing under may be advanced involves the fact that with equal heights of plants, good stands produce a larger tonnage than poor stands. Getting good stands is a matter of quantity and quality of seed, preparation of land, and methods and time of planting. Thirty pounds of winter peas per acre planted September 30 produced a larger crop of green material than did 60 pounds per acre planted October 26. Drilled vetch exceeded the yield of broadcast vetch by 30 percent when planted September 30 and by a larger percentage for later plantings. Similar results were obtained with Monantha vetch and winter peas.[8]

The fifth way of advancing the date of turning has been mentioned incidentally. Experiments show that there is nitrogen enough for the subsequent crop considerably earlier than farmers think. The pounds of nitrogen per acre in the tops and roots of vetch at the Georgia Experiment Station were 40 pounds on March 26; 43 pounds, April 2; 70 pounds, April 9; 85 pounds, April 16; 162 pounds, April 23; and 192 pounds, April 30. These would be equivalent to 260 pounds of nitrate of soda for the first date; 275 pounds for the second; 450 pounds for the third; 550 pounds for the fourth; 815 pounds for the fifth; and 1,240 pounds for the sixth.[9] If smooth vetch or winter peas had been used it is probable that the quantity of nitrogen would have been greater at the earliest date.

In the cases cited there was enough nitrogen for a crop of corn or cotton even at the earliest date mentioned; hence plowing should begin at about that time. The earlier a farmer begins plowing under winter legumes the longer the period of time in which plowing may continue, hence the greater the acreage per mule.

Grazing is another consideration. One successful Georgia farmer says he plants all his crop land in winter legumes, then grazes all of it. By careful management the season for plowing can be made still longer. The ungrazed portion can be plowed under first, then the remainder can be grazed in succession and plowed under in succession.

Some men cut their winter legume for hay and follow with corn or other late crop. Some cut it high, getting as much hay as they need and turning under the growth that is left. There are several ways of managing to get feed and fertilizer and to extend the time of plowing under the legume. It is estimated that a minimum of one third of the crop area can easily be handled in winter legumes.

PERCENTAGE OF CROP LAND IN WINTER LEGUMES

Small farms were found to have a larger percentage of their acreage in winter legumes than large ones (table 14). This may mean that the small farmer, who does most of his own work and does it better than do hired hands, is the one most likely to use winter legumes. Hired hands are prone to do a very poor job of turning under legumes.

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[8] BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Op. cit., tables 12 and 13.
[9] TEMPLE, J. C., THE VALUE OF AMMONIFICATION TESTS. Ga. Expt. Sta. Bul. 126, 17 p., 1919.

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TABLE 14.—*Percentage of crop land devoted to vetch and winter peas on farms of specified size*

Size group (crop acres per farm)	Farms [1]	Crop acreage		Acreage in vetch and winter peas		
		Total	Weighted average per farm	Total	Weighted average per farm	Percentage of crop acreage
	Number	*Acres*	*Acres*	*Acres*	*Acres*	*Percent*
0 to 50	50	2,096	42	355	7.1	16.9
51 to 100	109	8,842	81	903	8.3	10.2
101 to 200	115	19,284	168	1,783	15.5	9.2
201 to 400	49	13,880	283	802	16.3	5.8
401 to 600	43	23,825	554	1,129	26.2	4.7
Over 600	20	27,375	1,369	581	29.5	2.1
Total and weighted average	386	95,302	247	5,553	14.4	5.8

[1] Some farmers gave estimates for more than 1 year.

Nearly 6 percent of the crop area of the 386 farms shown in table 14 was in vetch and winter peas. Farms north of the latitude of 33° had 4.7 percent of their crop acreage in vetch and winter peas whereas those south of that latitude had 6.6 percent of the crop acreage in these legumes. The farther south, the earlier is the growth of the legume and the greater the length of time in which to plow it under.

According to the best information available, about 84,000 acres of winter legumes were planted in Georgia in 1928 and 90,000 acres in 1929. This is about 0.8 percent of the total crop acreage of the State. If the percentage were as large for the whole State as for the farms represented in this study there would have been more than 800,000 acres of these legumes, and if they should average 5 acres to the mile it would amount to 1,875,000 acres for the State.

HOME-GROWN WINTER-LEGUME SEED

Most of the crimson-clover seed used by farmers in the Carolinas and in Georgia is of their own saving, according to the records obtained. This seed is stripped off or is beaten out by forks and is sowed in the chaff. In most instances the seed is "scratched in" after being sowed on top of the ground. One farmer who is very successful with crimson clover says that when he sows the chaffy seed in cotton middles he scratches the ground first, then sows the seed, but does not cover; when he sows the thrashed seed he sows first and scratches afterward.

In certain years the seed crop of hairy vetch is a total failure because of the attacks of the corn ear worm. Even where this has not happened, the yield has been low. Then, too, the vetch seed shatters badly and in many districts no thrashing machines are available.

Some seed of Monantha vetch has been saved by a few farmers in southern Alabama. This vetch grows well with oats and ripens with the early varieties of oats, so they can be harvested together. On a few farms, where it was grown alone, it was allowed to become dead ripe and to fall flat on the ground. Then it was raked with a horse rake without cutting, the roots breaking off at the ground. The crop was then gathered and thrashed. Monantha vetch holds its seed well in the pod; its weakness is its lack of winter hardiness.

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With regard to winter peas, injury by aphids has been more or less prevalent, thus preventing seed formation, but the crop is usually large enough to turn under as a fertilizer before the aphids become abundant.

On the whole the prospects are not very encouraging for farmers to grow their own vetch and winter-pea seed.

CROPS PRECEDING AND FOLLOWING WINTER LEGUMES

About 80 percent of all the vetch and winter peas reported in this study were planted after cotton, as compared with 20 percent after all other crops. Vetch was planted after cotton in 211 cases, after corn in 24 cases, and after other crops in 29 cases out of a total of 264 cases; whereas out of 193 cases of winter peas, 157 followed cotton, 19 followed corn, and 17 followed all other crops. Among the "other crops" were cowpeas, soybeans, peanuts, and tobacco.

There are good reasons why it is the usual practice to plant winter legumes after cotton. Cotton middles are likely to be unoccupied whereas corn middles are usually planted with cowpeas, soybeans, peanuts, or velvetbeans. Then, cotton is laid by later than corn and the ground is cleaner, thus no preparation of the soil is required for the winter legume. Cotton stalks do not fall down across the rows as cornstalks frequently do in hard storms; thus there are no obstructions in the cotton middles.

It is comparatively easy to plant winter legumes after cowpeas, soybeans, peanuts, and tobacco, but the acreage of these crops is relatively small. If, in the organization of farms, a larger use could be made of cowpeas, soybeans, and peanuts, the practice of following them with winter legumes would increase.

Winter legumes are easily planted after tobacco. Crimson clover in North Carolina and winter peas in Georgia follow this crop to some extent. Tobacco does not follow these legumes because, although the resulting yield is good, the quality of leaf is not the best.

As to major crops that follow winter legumes, this study embraces 353 estimates for corn and 147 for cotton. It is clear that most farmers plant corn rather than cotton after winter legumes. Many would like to plant cotton after them, and about one third of those interviewed did so, but the complaint is made that the winter legume is not large enough to make much fertilizer when plowing for cotton should begin. This is partly true and partly not, as indicated under the heading Dates of Turning Legumes and of Planting the Following Crops. Those who use tractors can do better in this respect than those who use only mules.

Corn planting extends over a longer time than does cotton planting, hence there is more time to get the legume turned under and partly decayed before planting. Then, since cotton and corn are grown more or less in rotation or alteration, and since it is much easier to plant winter legumes after cotton than after corn, it is a natural sequence for the corn rather than cotton to follow the winter legume.

Crops other than cotton and corn following winter legumes were infrequent, but 2 cases of cowpeas, 4 of corn silage, 1 of sweetpotatoes, and 1 of sorgo silage were reported. In all cases the results were decidedly profitable. In two instances of corn silage the yield after vetch was equal to that on land which was manured at the rate of 10 tons of stable manure per acre,

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An interesting case was that of sorgo silage following bur clover for 10 consecutive years during which time the bur clover volunteered every year. On a farm in Saluda County, S.C., 6 acres of this clover on a red-clay hill were fertilized each year with 500 pounds of superphosphate per acre. Cattle and sheep were grazed on the clover in February and March, the estimated value of such grazing being $8 per acre. The 10-year average yield of the sorgo following bur clover was estimated to be 10 tons per acre compared with 5 tons per acre not after it. In April 1930, the stand of clover was good and the dark-green foliage indicated health and vigor. The average date for planting the sorgo had been June 1, after the bur-clover seed had matured. The type of soil and the heavy use of superphosphate are probably responsible for the excellent results.

CROP ROTATION AND WINTER LEGUMES

The acreage of winter legumes is so small at present that they do not constitute a definite part of any cropping system. But if they could occupy 20 to 35 percent of the total crop area they could easily be fitted into practical crop rotations. Rotations are rarely inflexible. Often something interferes with the regularity of a planned system. The failure of a particular crop, the exigencies of the weather, an unfavorable topography, or the varying types of soil on the same farm, limit the application of such rotations. Nevertheless, crop systems may be approximated and if one system will not apply on the whole farm it can often be divided into two or more systems for different parts of the farm.

A 3-YEAR ROTATION

A possible rotation in which winter legumes can be used is that described in table 15. In this rotation one third of the land is in cotton; one third in summer legumes for hay, seed, and pasture; and one third is in corn.

TABLE 15.—*A 3-year rotation of cotton, summer legumes, and corn*

Item	First field	Second field	Third field
First-year period	Cotton	Summer-legume hay etc., followed by winter legumes.	Corn and interplanted legumes.
Second-year period	Summer-legume hay, etc., followed by winter legumes.	Corn and interplanted legumes.	Cotton.
Third-year period	Corn and interplanted legumes.	Cotton	Summer-legume hay etc., followed by winter legumes.

The cotton may be replaced, if desired, by other money crops, like peanuts or tobacco. If hogs are to be raised for market, peanuts could be planted on part of the land assigned to summer-legume hay, etc., but the peanuts would have to be harvested in time to permit the land to be planted in winter legumes. Part of the same field might be planted to crops of early potatoes, cantaloupes, watermelons, or sorgo for sirup, all of which are harvested early enough so that winter legumes can be planted after them.

This 3-year rotation would produce more feedstuffs than the average southern farm would consume, two thirds of the area being

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assigned to feed crops, and the corn yield would be far above the average because this crop is preceded by winter legumes. It is, therefore, a rotation that assumes more livestock than the average southern farm possesses.

It may be asked why oats should not be introduced into this rotation where it would follow cotton and precede the summer legume. Perhaps there are farms on which this should be done but, in general, there is already more feed in this rotation than would be needed on the average farm, hence oats would merely add to the surplus feed, either of hay or grain. The date of planting the summer legume would be delayed as would the date of harvesting; there might not be time to plant the winter legume, depending on the latitude. At least, it would be easier to plant winter legumes after cowpeas and soybeans that are planted in April and May than after those planted in June. The winter legume should be planted in early October; if the double crop of oats-cowpeas interferes with this, the oats may well be omitted.

Another argument against oats in this rotation is the peak load of labor involved in June in harvesting the oats and planting the cowpeas. If oats-cowpeas are in the rotation a team could tend about 15 acres of cotton, 15 of oats-cowpeas, and 15 of corn; but if oats are omitted the team can tend 18 acres of cotton, 18 of summer legumes followed by winter legumes, and 18 of corn—or an increased acreage of 20 percent. This assumes a sandy loam soil in both cases and, in the latter case, it assumes that preparation of the old cotton land for summer legumes is by means of the disk harrow instead of the turnplow. If a tractor is used there would be about the same relative difference in acreage.

A further reason against oats for the average farm is the necessity of expensive harvesting and threshing machinery which the smaller farms cannot afford. There are conditions under which the oat crop is highly desirable but on the average farm and for the 3-year rotation described, its value is questionable.

The increased yield of corn following winter legumes has been found to average about 14 bushels per acre compared with corn not following the legume, hence on an 18-acre field the increased production of corn would amount to 252 bushels. Assuming a yield of 16 bushels per acre without the winter legume and 30 bushels per acre with it, the total production of corn on the 18 acres would be 288 bushels in the former case and 540 bushels in the latter.

With these yields, more corn can be grown on one fourth of the total land in crops when it follows a winter legume than on one third of the land without the winter legume. To illustrate: If 60 acres of crop land are available, then one fourth of the land, 15 acres, at 30 bushels per acre, will produce 450 bushels of corn whereas one third of it, 20 acres, at 16 bushels per acre, will produce 320 bushels.

A 4-YEAR ROTATION

With higher corn yields, the average southern farmer probably would prefer to have more than one third of his crop land in money crops and less than two thirds in feed crops, the proportions indicated for the 3-year rotation. Corn is not considered a money crop in the Southeast although a little is occasionally sold.

To increase the area of money crops and to decrease that of feed crops, a 4-year rotation is suggested, which may be considered the

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same as the 3-year rotation plus another equal field of a money crop, usually cotton. One half of the crop area in this rotation is devoted to money crops of which cotton is the principal one although peanuts and tobacco may replace cotton on part of the area if desired (table 16).

TABLE 16.—*A suggested 4-year rotation*

Item	First field	Second field	Third field	Fourth field
First-year period.	Cotton followed in part by winter legumes.	Cotton	Summer-legume hay etc., followed by winter legumes.	Corn and interplanted legumes.
Second-year period.	Cotton	Summer-legume hay etc., followed by winter legumes.	Corn and interplanted legumes.	Cotton followed in part by winter legumes.
Third-year period.	Summer-legume hay etc., followed by winter legumes.	Corn and interplanted legumes.	Cotton followed in part by winter legumes.	Cotton.
Fourth-year period.	Corn and interplanted legumes.	Cotton followed in part by winter legumes.	Cotton	Summer-legume hay etc., followed by winter legumes.

A variety of crops may occupy the field assigned to summer-legume hay, etc., if all can be harvested early enough to permit the planting of winter legumes to be turned under the following spring for corn. About half of this field may be devoted to cowpeas or soybeans for hay. A small area may be in the same crops to be harvested for seed or to be grazed off. A few acres may be devoted to such crops as early potatoes, cantaloupes, watermelons, peppers, and sorgo for sirup. There should be a greater flexibility in the plantings of this field than in the other fields.

Part of the cotton land may be planted to winter legumes to be turned under the next spring for cotton or peanuts but the acreage will have to be limited or there will be too many acres of winter legumes to plow under in the limited time available for the purpose. Corn follows winter legumes in this 4-year rotation, as in the 3-year rotation, and may be interplanted to cowpeas, peanuts, soybeans, or velvet beans.

If the old cotton land is prepared for the summer legumes, with a disk harrow, one team will tend about 52 acres of all crops in this 4-year rotation which means 13 acres to each of the four fields. With a yield of 30 bushels per acre of corn the 13 acres will produce 390 bushels; this is about 100 bushels more than enough for home requirements on a 2-horse farm. It would require a little extra livestock to consume this surplus corn but perhaps that is not an objection. Extra cows would require extra hay and the area assigned to summer legumes is sufficient for feeding two or three extra cows. A few more hogs would help to consume the extra corn and the by-products from the cows.

ADAPTATION TO SHARE-CROP CONDITIONS

A serious difficulty in applying definite crop rotations to farms in the Cotton Belt is the fact that the share cropper who raises much of the cotton for a half share of the crop has little use for feed crops. He prefers to grow cotton continuously on the same land. Even when the landlord persuades the share cropper to raise corn and other feed crops, the latter is not interested and the landlord usually buys the share cropper's half of these feedstuffs.

Some lands are better for cotton than for corn and the tendency is to grow cotton more or less continuously on certain parts of the

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farm or plantation. In the attempt, therefore, to apply crop rotations to the Cotton Belt it may be well to apply them to part of the farm and let cotton be grown continuously on other parts. If hogs are raised, crops that they can graze must be grown in fenced fields adjacent to their buildings. These may be in a rotation by themselves.

To illustrate a plan of growing cotton continuously on part of the farm, or plantation, and of using crop rotations on other parts of the farm the following example is given for 60 acres of crop land. One field of 20 acres will be devoted to continuous cotton production, and two fields of 17 acres each will be devoted to a 2-year rotation of crops as follows:

First year	10 acres of cotton, peanuts and/or tobacco, in varying proportions, followed by winter legumes.
	7 acres of summer legumes for hay and seed, followed by winter legumes.
Second year	12 acres of corn and interplanted legumes.
	2 acres of melons or substitute crop followed by winter legumes.
	3 acres of summer legumes for hay and seed followed by winter legumes.

In addition there will be two fields of 3 acres each on which a rotation of grazing crops for hogs will be grown. This rotation will be as follows:

First year	Corn and interplanted legumes.
Second year	Peanuts, Sudan grass, etc., for grazing.

This arrangement puts half the land in the money crops of cotton, peanuts, and (or) tobacco. Part of the 2 acres of melons or substitute crops, like early potatoes or sorgo sirup, may also be sold. One fourth of the land is put in corn and interplanted legumes (12 acres plus 3 acres); one sixth in summer legumes, such as cowpeas and soybeans, for hay and seed (7 acres plus 3 acres), and one twentieth in peanuts, Sudan grass, etc., for grazing by hogs.

If there is time to plant and turn under a larger acreage of winter legumes than has been planned for in the foregoing examples they can occupy part of the land devoted to continuous cotton. Their growth does not interfere with the growth of cotton unless they are turned under too late in the spring.

In southern Georgia and Alabama one team of two mules can tend this 60 acres of crops. The share cropper, if there is one, might tend the 20 acres of continuous cotton and he could work as a wage hand part of the time on feed crops.

If the acreage of continuous cotton shown in the foregoing plan is too large it can be reduced, and the rest of the land devoted to a 3-year crop rotation. A method of doing this would be to have one fourth of the land, or 1 field of 15 acres, devoted to continuous cotton production, and 3 fields of 13 acres each devoted to the 3-year rotation, as follows:

First year	13 acres of cotton, peanuts, and (or) tobacco in varying proportions.
Second year	10 acres of summer legumes for hay and seed followed by winter legumes.
	2 acres of cotton followed by winter legumes.
	1 acre of melons followed by winter legumes.
Third year	12 acres of corn and interplanted legumes.
	1 acre of melons or substitute crop.

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In this system, as in the previous one, there will be a rotation of grazing crops for hogs on 2 fields of 3 acres each, in the following order:

First year..... Corn and interplanted legumes.
Second year..... Peanuts, Sudan grass, etc., for grazing.

In this arrangement the acreage of money crops and of feed crops is the same as in the preceding plan but the acreage in continuous cotton is only one half of all the acreage in cotton, peanuts, and tobacco, whereas in the previous arrangement it was two thirds of all cotton, peanuts, and tobacco. It would be easy to make the acreage of continuous cotton still smaller and arrange the remainder of the land in a crop rotation. All of the crops following the 10 acres of summer legumes, 2 acres of cotton, and 1 acre of melons in the last-mentioned plan are to be followed by winter legumes. Substitutes for melons may be early potatoes, and sorgo for sirup.

Any of these systems or any other that may be suggested might have to be modified in particular cases. There are certain areas of wild meadow hay that are not suitable for any other crop; there are lands suitable for corn that are not suitable for cotton; and in certain places modifications are required because of the topography of the fields. Within these limitations, however, a rotation system that provides for better yields of all crops, that gives ample acreages for the money crops and for feed crops, and that provides a reasonable distribution of labor for man and horse, is much to be desired.

The general use of winter legumes in the Southeastern States would still leave cotton and corn as the principal crops. It would not be likely to increase the corn acreage but would decidedly increase its total production. To the extent that cotton follows winter legumes it would be benefited directly; in any event, it would be benefited indirectly. The use of these legumes in preventing soil erosion and in furnishing hay and pasture is highly desirable, but their main use is in building the fertility of southern soils.

SUMMARY

This study was made in North Carolina, South Carolina, Georgia, and Alabama in 1929 and 1930.

The number of 1-year estimates was 353 for corn and 147 for cotton; of these 500 estimates, 264 were for crops after vetch, 193 for crops after winter peas, 32 for crops after crimson clover, and 11 for crops after bur clover.

The increased yield of corn after winter legumes averaged 14.1 bushels per acre; of cotton, 100 pounds of lint per acre.

The total extra cost for corn after winter legumes on 4,145 acres, over and above that on corn not after winter legumes, was $5.54 an acre on the basis of high prices, of which $2.87 was cash cost and $2.67 was noncash. At low prices the same items were $1.88 and $1.48 respectively.

The total extra cost for cotton after winter legumes on 1,877 acres, over and above that on cotton not after winter legumes, was $8.61 an acre at high prices, of which $3.80 was cash cost and $4.81 was noncash. At low prices these items were $2.39 an acre and $2.52 an acre respectively.

The net gain in value from the use of winter legumes for corn was $9.19 an acre at high prices, all costs considered, or $11.86 an acre

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with cash costs only considered. At low prices the net gain would be $3.99 an acre, all costs considered, or $5.47 an acre if only cash costs are considered.

The net gain in value from the use of winter legumes for cotton was $9.69 an acre at high prices, all costs considered, or $14.50 an acre with only cash costs considered. At low prices the net gain would be $2.24 an acre, all costs considered or $4.76 with only cash costs considered.

The increased yield of corn after winter legumes was 2.1 bushels per acre greater on land south of latitude 33° than on land north of that line. The increase in yield of lint cotton was 10 pounds per acre greater south of latitude 33°.

Winter legumes have a residual effect the second year after planting according to the testimony of many farmers. This is confirmed by experimental evidence.

The grazing value of winter legumes is sufficient to pay all expenses, and even after grazing the fertilizer value is considerable.

In 79 percent of the cases studied there was no preparation of land before the winter legume was planted, because it was planted in the middles between row crops, mostly in cotton middles. In 12 percent of the cases the land was flat broken and in 9 percent it was disked and harrowed.

In 53 percent the winter-legume seed was broadcast and harrowed in or plowed in; in 47 percent it was drilled in.

The average rate of seeding winter legumes was 23 pounds per acre for vetch and 31 pounds for winter peas; the average price of vetch seed was 13 cents and of winter pea seed 9½ cents a pound.

In 179 cases out of 500 the winter legumes were fertilized at an average rate of 328 pounds of commercial fertilizers per acre. In the other 321 cases no fertilizer was used.

Pure-culture inoculation is commonly used on winter-legume seed, especially the first time they are planted on any piece of land. Many farmers also use soil from an old field that has grown the same kind of legume. Using both is called the double method.

In 373 of 459 cases the winter legume was plowed under in the spring without preliminary disking and in the rest of the cases it was disked once or twice before planting.

The rolling colter attachment to plows is little used but ought to be used everywhere to do a good job of covering winter legumes and, if growth is large, the plow should have a "slide" to press the growth down, or a heavy chain to drag it down.

The average time between the date of turning under winter legumes, including both vetch and winter peas, and planting corn thereafter, was 14 days at points north of the latitude of 33° and 17 days at points south of it. For cotton it was 17 days north and 19 days south of that line.

Most farmers think that 5 acres of winter legumes per mule is the practicable number, but with proper management and implements this acreage can be increased to 10 or more acres.

Experimental evidence shows that October 1 plantings of winter legumes make larger yields than plantings 3 or 4 weeks later; this is especially true of the early spring growth. Such evidence also shows that Austrian winter peas and Monantha vetch usually make a larger early growth than does hairy vetch.

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The date of beginning to plow under the winter legume can be advanced by getting a larger early spring growth. This can be done by (1) using fertilizer on the legume, (2) planting the legume early in the fall, (3) using the kind of legume that makes the largest early growth, and (4) getting good stands of the legume.

The percentage area of winter legumes is greater on small farms than on large ones, and greater south of 33° latitude than north of that line.

About 80 percent of the winter legumes on the farms studied were preceded by cotton, 10 percent by corn, and 10 percent by all other crops. Seventy percent of these legumes were followed by corn and nearly all the rest by cotton.

Cowpeas grown for hay, corn silage, sorgo silage, and sweetpotatoes were found to be benefited by fertilizing with winter legumes.

Winter legumes can be fitted into various crop rotations. One fifth to one third of the crop land should be in winter legumes and even more if there are animals to graze the fields.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

CHANGES IN QUANTITY AND COMPOSITION OF FAT IN HOGS FED A PEANUT RATION FOLLOWED BY A CORN RATION [1]

By N. R. ELLIS, *Chemist, Animal Husbandry Division, Bureau of Animal Industry* [2]

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THE RELATION OF PEANUT FEEDING TO SOFT PORK

When peanuts are fed to hogs as the basal constituent of the ration, the fat deposited in the adipose tissues is not greatly different in composition from the ingested peanut oil. The carcasses of hogs thus fed are soft or oily even after thorough chilling, in contrast with the firm carcasses of hogs which have received hardening feeds throughout life.

Experiments (*4*, *5*)[3] have shown that a gradual hardening of the adipose tissue takes place when a ration of corn and nonsoftening supplements is fed after the peanut ration. In general, the greater the gain on the peanut ration the greater the gain on the hardening ration that is required to produce a given degree of firmness of the adipose tissue in the chilled carcass or a given fat-constant value of the fat. These results, which are based on a large number of hogs self-fed in groups, have shown that, when the initial weights of the hogs exceeded 85 pounds, moderate firmness was not attained until the gain on the hardening ration was more than three times that on the softening ration. In the usual case the gain on the peanut ration was more than 40 pounds, with the result that the hogs weighed 300 pounds or more before moderate firmness was attained. In addition

[1] This work was conducted as a part of the project, cooperative soft pork investigations, which later was combined with the national project, cooperative meat investigations. Work on the firmness of fat of peanut-fed hogs, of which the experiments in the present study formed a part, has been conducted by the agricultural experiment stations of Georgia, Mississippi, North Carolina, South Carolina, and Virginia, in cooperation with the Bureau of Animal Industry, U.S. Department of Agriculture.

[2] H. S. Isbell and S. J. Dahl, of the Animal Husbandry Division, assisted the author materially in obtaining the data. E. Z. Russell, O. G. Hankins, and J. H. Zeller, of the same division, provided the experimental animals for the laboratory work, and K. F. Warner, also from this division, slaughtered the animals and prepared the carcasses for analysis.

[3] Italic numbers in parentheses refer to Literature Cited, p. 13.

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to their excessive weight and degree of finish, these hogs varied widely in firmness from soft to hard.

Better success in hardening has attended the feeding of hogs with initial weights of less than 50 pounds. A report (*7, p. 9*) of this work shows that lightweight pigs which gained from 20 to 60 pounds on a peanut ration and, later, 190 pounds on a corn-and-tankage ration usually produced carcasses of a satisfactory firmness.

These results indicated that the weight at the beginning of the peanut feeding, as well as the ratio of softening to hardening gain, materially influenced the firmness of the carcass. The underlying reasons for these general relationships, together with the exceptions and variations, remained for further study.

Since the firmness of pork is dependent in large measure on the composition of the fat (*2*), it is only reasonable to assume that the increase in firmness which occurs in the hardening of peanut-fed hogs is intimately related to the admixture of firm body fat with the oily fat previously stored. It follows that the composition and firmness of the fat in the adipose tissue at slaughter will be dependent on the proportions and the composition of the soft and hard fats stored during the two feeding periods.

The hog normally deposits fat at an increasingly rapid rate per unit of live-weight increase, within limits, when no important changes in the ration are made (*1*). Thus, on a ration of corn with nonsoftening supplements, hogs store more fat during the period of weight increase from 200 to 250 pounds than during the period of weight increase from 50 to 100 pounds.

Evidence from early experiments indicated that feeds of high oil content, such as peanuts, accelerated fat deposition above the normal rate. It is difficult, therefore, to predict from the gains in weight the probable gain in fat in the successive feeding periods on the peanut and the corn rations.

The differences in fatness between carcasses of hogs of similar weight are frequently of such magnitude that they are evident on cursory examination. Lack of finish has been found to be associated with softness of the carcass (*4*).

OBJECT OF STUDIES

Studies on the function of body-fat storage in the hardening of peanut-fed hogs were prompted by these considerations. The chief object of these studies was to determine the underlying factors involved in fat deposition in the hog when both softening and hardening feeds were used. Attention has been given not only to the influence, on firmness, of the proportions of body fat stored during successive periods on softening and on hardening feeds but also to the variations due to differences in rates of fat storage. A rather complete study has been made of the quantity of fat deposited and the composition of this fat.

EXPERIMENTAL WORK

These experiments were carried out at the United States Animal Husbandry Experiment Farm at Beltsville, Md. Since information was desired on the approximate quantity and composition of the body fat at the beginning of the experiment, at the close of the peanut-

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feeding period, and at intervals during the hardening period, killings of representative animals were made at appropriate intervals.

All pigs were reared under the same conditions but not during the same year. Nonsoftening feeds were used in the rations of the sows and of the pigs up to the beginning of the experiments. The Chester White, Berkshire, Duroc-Jersey, and Poland China breeds were represented.

The group of hogs constituting lot A in the present study averaged approximately 100 pounds in weight at the beginning of the experiment. Their softening ration contained whole peanuts and a mineral mixture, self-fed. Lot B consisted of pigs which averaged approximately 40 pounds at the beginning of the experiment. Their softening ration included tankage, whole peanuts, and a mineral mixture, also self-fed. Although well-developed hogs, such as those in lot A, make satisfactory gains on peanuts and mineral mixture, experiments have shown that immature weanling pigs weighing less than 50 pounds apparently require additional supplements. In view of the work of Hankins and Zeller (*6*), tankage was added to the peanuts and minerals in the ration of lot B, though another supplement might have served equally well, as shown by experiments of Halverson, Hostetler, and Sherwood (*3*). They concluded that alfalfa meal and a mineral mixture were the only additional supplements to peanuts necessary to produce satisfactory gains in pigs ranging from 35 to 60 pounds. No work has been reported on the value of these supplements for hogs weighing 100 pounds or more.

Since the gains of the heavyweight pigs without tankage and of the lightweight pigs with tankage have been regarded as normal and satisfactory, comparison of the results of the two lots has been made. The main question involved, that of rate of fat deposited in relation to total gain, is not believed to be seriously affected by the difference in feeding with regard to tankage. Information gained during the progress of numerous soft-pork experiments has attested to the fact that extreme changes of diet are necessary to influence the fatness of the body. Thus, the restriction of the feed intake of a peanut ration to one-half of a full feed level failed to reduce materially the rate of fat storage.[4]

Following the feeding period on the peanut ration, on which the hogs in lot A were usually permitted to gain from 50 to 60 pounds and those in lot B from 40 to 50 pounds, a hardening ration of yellow shelled corn, tankage, and a mineral mixture was given. The groups of hogs continued on the self-feed basis.

Three of the hogs in lot A were killed for analysis at the beginning of the experiment. Three were killed at the end of the peanut-feeding period, when they had gained an average of 58 pounds on the softening ration. Finally, eight representative animals were slaughtered singly or in pairs after their gains on the hardening ration had reached multiples of approximately 2, 2.5, 3, 3.5, 4, and 5 times their gains on the softening ration.

The composition of the 40-pound pigs in lot B at the beginning of the peanut-feeding period was based on analyses made during the course of other experiments conducted over a somewhat longer period

[4] ELLIS, N. R., and ZELLER, J. H. THE EFFECTS OF LIMITATION OF THE FEED ON THE ECONOMY OF GAIN AND THE COMPOSITION OF THE BODY OF HOGS. [Unpublished manuscript.]

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than the present ones. However, three pigs were killed at the end of the peanut-feeding period, when they had gained an average of 48 pounds on the softening ration. The remaining six animals in lot B were slaughtered during the hardening period, their gain multiples ranging from 2 to 5, like those in lot A.

After the hogs were removed from the feed lot for slaugher, they were kept without feed for a 24-hour period, were weighed, and then slaughtered. Since an estimate of the total quantity of fat in the entire body was required, the samples prepared for analysis included those body parts known to contain significant quantities of fat. All parts were included except the hair and toes, which were removed in the scraping process. The viscera and blood were sampled immediately after slaughter. The carcasses were chilled and graded for firmness (*4*). After fat samples had been taken, the carcasses were divided into commercial cuts and separated on a total-carcass basis into skin, bone, and meat fractions. Analyses for water, protein (N. times 6.25), fat (ether extract), and ash were then made. The composition of the entire body was calculated from the analyses of the parts. The total thus obtained was termed the "total analyzed weight."

Fat analyses were made of samples of back and leaf fats taken according to a routine procedure (*4*) and of samples of fat prepared from the meat fraction as samples for body analysis. The fat analyses included refractive index, iodine number, melting point, and titer test on part or all of the samples, together with lead-salt separations made of the meat fat. From these separations of the fat the percentages of mixed saturated, oleic, linoleic, and arachidonic acids were estimated (*2*).

The data from the analyses have been used to estimate the weight of the several body constituents present in the animal body and the gain in the total fat and fat fractions preceding the experimental period and during the softening and the hardening periods.

RESULTS OF EXPERIMENTS

FEED CONSUMPTION

The average feed consumption (table 1) of the hogs, as judged from the results for the group from which they were selected, was typical of that commonly obtained with hogs on the rations used (*4*). From tables 1 and 2 it may be seen that the quantity of the peanut ration consumed per unit of gain was lower than that of the corn ration. The large quantity of peanut oil ingested, as indicated by the ether extract of the peanuts, readily accounts for the extreme softening of the body fat which always occurs. From the feed-consumption and the feed-analysis data it was estimated that the lot A hogs consumed 121 pounds and the lot B hogs 95 pounds of peanut oil for every 100 pounds of gain in live weight which they made during the softening period. The ingestion of these high levels of oil is especially noteworthy, as is shown later in the effects on the quantity and composition of the oily fat stored by the hogs.

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TABLE 1.—*Quantity of feed and calculated ether extract consumed per 100 pounds of gain by 2 lots of hogs of different initial weights*

Feeding period and feeds used	Lot A (100 pounds initial weight)		Lot B [1] (40 pounds initial weight)	
	Total feed	Ether extract	Total feed	Ether extract
Softening:	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Shelled peanuts [2]	276.0	121.0	211.0	94.8
Tankage			46.0	3.1
Mineral mixture	9.3		2.0	
Total	285.3	121.0	259.0	97.9
Hardening:				
Shelled corn	513.5	19.5	349.6	13.7
Tankage	28.1	1.8	48.5	3.3
Mineral mixture	6.0		1.3	
Total	547.6	21.3	399.4	17.0

[1] Data from the 3 lot B hogs killed at the end of the softening period not included.
[2] Weight of shelled peanuts was about 69.5 percent of the weight of the whole peanuts fed.

TABLE 2.—*Weights and gains of 2 lots of hogs of different initial weights on the softening and hardening rations*

LOT A (100 POUNDS INITIAL WEIGHT)

Hog no.[1]	Breed [2]	Initial weight	Total gain on—		Average daily gain on—		Approximate gain ratio	Weight at close of feeding period
			Softening ration	Hardening ration	Softening ration	Hardening ration		
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*		*Pounds*
4	CW	100	57		0.74			157
5	Mix	98	59		.79			157
6	B	99	58		.62			157
Average		99	58		.72			157
7	B	109	60	125	.87	0.74	1:2.1	294
8	Mix	106	61	152	.88	.77	1:2.5	319
9	DJ	100	60	153	1.05	1.17	1:2.6	313
10	PC	102	58	174	.91	1.51	1:3.0	334
11	H	95	53	187	.95	1.29	1:3.5	335
12	CW	104	56	196	.90	1.21	1:3.5	356
13	B	114	51	207	.91	1.36	1:4.1	372
14	PC	109	54	282	.96	1.68	1:5.2	445
Average		105	57	185	.93	1.22	1:3.25	346

LOT B (40 POUNDS INITIAL WEIGHT)

15	PC	39	34		0.41			73
16	CW	38	51		.61			89
17	CW	38	58		.69			96
Average		38	48		.57			86
18	PC	40	43	86	.77	1.54	1:2.0	169
19	DJ	52	39	81	.70	1.45	1:2.1	172
20	PC	48	47	135	.84	1.65	1:2.9	230
21	CW	30	43	200	.77	1.43	1:4.7	273
22	CW	38	44	195	.79	1.39	1:4.4	277
23	PC	47	40	203	.71	1.84	1:5.1	290
Average		43	43	150	.76	1.55	1:3.5	235

[1] Hogs 1 (CW), 2 (CW), and 3 (Mix) were slaughtered previous to the softening period.
[2] CW, Chester White; B, Berkshire; DJ, Duroc-Jersey; PC, Poland China; H, Hampshire; Mix, mixed breeding.

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WEIGHTS AND GAINS OF HOGS

The data on weights and gains of the two lots of hogs for the softening and the hardening periods are given in table 2. As a group, the lot A hogs gained more rapidly than the lot B hogs on the peanut rations. However, the difference probably is no greater than that between 100-pound and 40-pound pigs on other feeds. At the close of the hardening period, in lot A 7 of the 8 hogs weighed more than 300 pounds each. In lot B, the maximum weight was 290 pounds.

The approximate gain ratio between softening and hardening periods is also given in table 2. In lot A a ratio of 1:2.5 was associated with a final weight of more than 300 pounds, whereas in lot B a ratio of 1:5.1 was possible for a hog which weighed 290 pounds. In lot B the smaller gain on the softening ration was an important factor in keeping the final weight at less than 300 pounds when the total gain on hardening feed was sufficient to give a ratio of 1:5.1.

COMPOSITION OF THE BODY

The age of the hogs at slaughter, the slaughter and analysis weights, and the percentages of water, protein, fat, and ash in the carcasses are given in table 3.

TABLE 3.—*Slaughter weights and composition of bodies of hogs used in experiment*

Hog no.	Age at slaughter	Weight at slaughter	Total analyzed weight	Composition of body			
				Water	Protein	Fat	Ash
	Days	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
LOT A (100 POUNDS INITIAL WEIGHT)							
1	202	94	87.8	57.84	13.95	25.60	2.60
2	204	100	94.0	58.90	14.46	24.08	2.61
3	205	98	91.3	56.20	14.35	26.88	2.59
Average	203	97.3	91.0	57.65	14.25	25.52	2.60
4	264	150	142.3	46.60	12.30	38.70	2.35
5	262	151	145.8	45.99	10.83	41.24	1.97
6	290	153	145.3	48.05	13.25	36.65	2.12
Average	272	151.3	144.5	46.88	12.13	38.86	2.15
7	427	294	284.4	38.29	11.31	47.89	2.51
8	462	301	298.5	36.31	11.18	50.65	1.84
9	403	310	292.6	36.90	10.33	51.15	2.00
10	416	334	308.6	38.80	10.70	48.55	2.15
11	394	335	316.4	38.64	10.88	48.50	2.00
12	423	353	334.9	35.30	9.84	52.80	2.05
13	398	370	351.2	42.29	12.20	43.12	2.44
14	415	445	433.0	35.20	9.73	53.19	1.92
Average	417	342.8	327.4	37.72	10.77	49.48	2.11
LOT B (40 POUNDS INITIAL WEIGHT)							
Average of 3 pigs taken from other experiments	77	41	38.3	60.82	15.52	20.41	3.45
15	166	73	68.1	53.20	12.11	32.73	2.26
16	177	84	72.2	51.84	13.08	31.72	3.10
17	179	90	83.5	52.32	13.42	31.68	2.54
Average	174	82.3	74.6	52.45	12.87	32.04	2.63
18	211	164	153.6	46.09	11.44	40.16	2.51
19	211	165	157.0	46.53	11.76	39.32	2.57
20	237	229	221.7	41.27	10.94	45.53	2.31
21	295	268	257.3	37.42	9.51	51.24	2.16
22	295	275	259.5	37.34	9.48	51.17	2.13
23	265	277	264.3	39.91	9.91	47.71	2.28
Average	252	229.7	218.9	41.43	10.51	45.86	2.33

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The results of particular interest on composition of the carcass are those on fat content. In lot A the fat content of the three hogs analyzed at the beginning of the softening period averaged 25.52 percent. The three hogs analyzed at the close of the softening period had a much higher fat content, 38.86 percent. The increase made by the hogs in lot A was greater than that made by those in lot B, the percentages of fat content for lot B before and after peanut feeding being 20.41 and 32.04, respectively. Furthermore, hogs 15, 16, and 17, which were slaughtered at the end of the peanut-feeding period, were fatter than hogs 1, 2, and 3, which had received only nonsoftening feeds, even though the latter group averaged 15 pounds more in weight. It is apparent, therefore, that the peanut ration caused a greater increase in fatness than normally occurs on rations low in fat, such as corn and tankage.

A corresponding increase over the normal occurred in hogs 4, 5, and 6. Hogs of similar weight [5] fed on rations of corn with nonsoftening supplements had a fat content of approximately 32.5 percent, which is about 6.3 percent less than the average fat content of hogs 4, 5, and 6. Furthermore, hogs 15, 16, and 17 were as fat at slaughter weights of from 73 to 90 pounds as these corn-fed hogs, which weighed approximately 150 pounds. The apparent excessive fattening which occurred in both lots A and B during the softening period is of particular importance in its bearing on the hardening requirements of the hogs. During the hardening period, in general the increase in fatness continued but was less rapid. There were exceptions in both lots, hog 13 in lot A and hog 23 in lot B having especially low fat contents as compared with others of similar weights.

In the grading of carcasses for firmness in the cooperative meat investigations already mentioned, hog carcasses are divided into five grades: Hard, medium hard, medium soft, soft, and oily. All grades are represented in this experiment (table 4). Hogs 1, 2, and 3, used as controls for lot A, were moderately soft, as shown by gradings of soft and medium soft. These are the usual gradings of hogs of 100 pounds weight or less (*4*). The three laboratory animals used as controls for lot B were not graded, although the fat constants given in table 4 indicate moderate softness. Peanut feeding produced a pronounced change toward oiliness in both lots. Five of the six hogs, nos. 4, 5, 6, 15, 16, and 17, were graded oily. The refractive index and iodine numbers show corresponding changes.

The data for hogs 15, 16, and 17 indicate that the fat of these animals was more oily than that of hogs 4, 5, and 6. This does not mean that in the former group there was deposited a fat of a correspondingly greater degree of oiliness than in the latter group, although some differences could be expected because of age or stage of growth. As already indicated, the difference can be accounted for in large measure by the fact that at the beginning of the softening period the hogs in lot A, because of their greater age and weight, had a larger quantity of moderately soft fat to which was added the oily fat deposited on the peanut ration. Although a change of the oily condition to one of moderate softness occurs relatively rapidly after changing to the hardening ration, a comparison of gradings of the lot A hogs killed at intervals during the hardening period fails to show

[5] Unpublished data.

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a consistent increase in firmness beyond that of soft, with widening of the gain ratio. The heaviest hogs, nos. 13 and 14, with approximate gain ratios of 1:4.1 and 1:5.2, respectively (table 1), were both medium soft. Hogs 11 and 12, intermediate in weight, were graded medium hard and hard, respectively. They had lower refractive index and iodine-number values than hog 10, which had a narrower gain ratio and was graded soft.

TABLE 4.—*Firmness grades, fat constants, and fatty-acid distribution of carcasses of hogs* [1]

LOT A (100 POUNDS INITIAL WEIGHT)

Hog no.	Firmness grade of carcass [2]	Refractive index, 40° C.			Meat fat			Fatty acids (meat fat)					
		Meat fat	Back fat	Leaf fat	Iodine number	Melting point	Titer test	Iodine number total unsaturated	Mixed saturated	Unsaturated			
										Oleic	Linoleic	Arachidonic	Total
					°C.	°C.			Percent	Percent	Percent	Percent	Percent
1	MS	1.4601	1.4603	--------	70.5								
2	S	1.4599	1.4601	--------	68.4	------	37.1	111.1	33.0	48.2	14.0	0.14	62.3
3	MS	1.4604	1.4602	--------	73.1								
4	S	1.4614	1.4614	1.4607									
5	O	1.4620	1.4621	1.4616	84.1	22.5	30.7	113.7	22.6	54.2	18.4	.18	72.8
6	O	1.4618	1.4618	1.4613									
7	S	1.4599	1.4600	--------	69.9	27.9	------	103.0	27.5	58.0	9.4	.09	67.5
8	S	1.4602	1.4602	1.4595	73.3	33.8	------	104.9	26.9	57.2	10.8	.08	68.1
9	S	1.4600	1.4599	1.4596	71.9	29.8	------	103.9	28.6	56.3	10.0	.06	66.3
10	S	1.4603	1.4602	--------	73.3	33.1	------	103.8	26.5	57.9	10.1	.09	68.0
11	MH	1.4601	1.4602	1.4599	70.7	35.5	------	103.1	27.2	58.4	9.5	.08	68.0
12	H	1.4598	1.4599	1.4596	71.3	28.6	------	100.6	27.0	60.1	7.7	.08	67.9
13	MS	1.4602	1.4602	1.4592	71.4	32.7	------	103.9	27.5	56.5	10.0	.07	66.5
14	MS	1.4599	1.4599	1.4591	68.1	-------	------	103.0	29.2	56.8	9.5	--------	66.3

LOT B (40 POUNDS INITIAL WEIGHT)

(3)	--------	1.4605	--------	1.4600	74.6	26.4	------	112.0	28.5	51.0	15.3	0.02	66.5
15	O	1.4632	1.4630	1.4632	94.5								
16	O	1.4631	1.4628	1.4625	91.5	------	29.4	117.5	18.9	53.5	23.1	.05	76.6
17	O	1.4629	1.4624	1.4628	91.7								
18	MS	1.4607	1.4601	1.4598	70.0	-------	33.6	105.4	29.2	55.1	11.2	.05	66.3
19	MS	1.4602	1.4601	1.4593	67.4	-------	34.5	105.3	31.2	53.5	10.8	.04	64.3
20	MH	1.4600	1.4595	1.4591	65.6	-------	36.1	102.6	31.9	54.7	8.8	.04	63.5
21	H	1.4596	1.4593	1.4591	62.5	-------	36.1	103.4	33.7	52.1	8.9	.04	61.0
22	H	1.4598	1.4593	1.4592	62.8	-------	36.1	102.5	33.0	53.9	8.5	.02	62.4
23	MS	1.4597	1.4595	1.4592	62.0	-------	36.2	104.2	33.2	52.6	9.7	.03	62.3

[1] In the cases indicated by blanks the analyses were not made. Both titer tests and melting points were considered unnecessary in the usual case.
[2] H, hard; MH, medium hard; MS, medium soft; S, soft; and O, oily.
[3] Average of 3 pigs taken from other experiments. Carcasses not graded for firmness.

Apparently the medium soft grades of hogs 13 and 14 may be explained by their relatively low fat content. Table 3 shows an abnormally low fat content for hog 13, whereas hog 14 had a value similar to that of hog 12, although the former was approximately 100 pounds heavier. In other words, had the proportionate increase in fatness according to weight of animal occurred, hog 14 should have attained a value considerably above 53.19 percent. Further discussion of the relation of fat content to firmness is given later.

In lot B an orderly increase in firmness, as determined by gradings and fat constants, occurred in hogs 18 to 22, inclusive. Hog 23 was graded medium soft, although the fat constants indicate firm fat.

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This hog had a low content of body fat, as compared with hogs 21 and 22, which were only a few pounds lighter in weight (table 3). Possibly its adipose tissues were not so extensive nor so completely filled with fat, a finding which has been frequently observed (*5*).

With gain ratios comparable for the two lots, the hogs in lot B generally had greater firmness than those in lot A. The decrease in iodine number from a maximum of 94.5 for one of the hogs slaughtered at the close of the softening period to a minimum of 62 shows the marked change in fat composition which it is possible to produce under the feeding conditions used in lot B.

Comparison of the firmness data of these hogs with the data of other hogs from the same feeding experiments showed that the animals selected for the present study were typical for the various weights and gains represented in the groups. For the other hogs there were similar discrepancies in the relationship between increasing firmness and widening of the gain ratio or increase in weight, with extremes of hard and soft among individuals with gain ratios of 1:4 or wider.

In line with the marked changes, due to the hardening ration, in the values for the fat constants, especially in lot B, the content of the mixed saturated and the unsaturated acids in the body fats of the hogs show definite and characteristic changes.

The results of fatty acid separations are given in table 4. The mixed saturated acids obtained by the lead salt-ether method of separation were not further fractioned. The unsaturated acids which were identified were oleic, linoleic, and arachidonic. As in an earlier work (*2*), the arachidonic acid was identified from its bromine addition product. It occurred in relatively small quantities and, although considerable importance has been attached to its presence in animal tissues during recent years, it played little part in the softness of the pork.

The decrease in the mixed saturated acids and increase in the linoleic acid to approximately equal levels in the lard of peanut-fed hogs have been previously observed (*2*). The changes during the hardening period were not so marked in lot A as in lot B and are in harmony with the firmness gradings and fat constant values. In lot A the failure of the mixed saturated acids to reach 30 percent or more appears to have been an important factor in explaining why so few hogs were hard or medium hard. The single animal which was graded hard had a low value of 7.7 percent for linoleic acid, although the oleic acid content was the highest for the group.

Comparison of the values for mixed saturated acid and for oleic acid shows a tendency toward lower mixed saturated and higher oleic acid content in hogs 7 to 14 in lot A than in hogs 18 to 23 in lot B. The reasons for the increase in percentage of mixed saturated acids in hogs 18 to 23 are not apparent, although the fact that these hogs were younger than hogs 7 to 14 when they were fed the softening ration was undoubtedly of primary importance. Similar differences between groups fed under the same feeding plan but at different experiment stations were observed in the work already mentioned (*2*).

The variations among individuals in lots A and B, as well as differences between lots, in both the fat content of the body and the percentages of fatty acids in this fat have been such as to account in large measure for the failure of certain hogs to attain the normal degree of firmness expected from the gains in weight. The percentages of

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fatty acids are necessarily influenced by the quantity of fat as a whole which is stored in the successive feeding periods. In view of this, it seemed desirable to calculate for each hog the quantities of total fat and of the principal fatty acid fractions deposited in each feeding period, including the period previous to the experiment.

These calculations were based on the data in tables 2, 3, and 4 and other data in the laboratory. The quantities of the fatty-acid fractions are shown in figures 1 and 2. The values for the average composition of hogs 1, 2, and 3 furnish the means for estimating the composi-

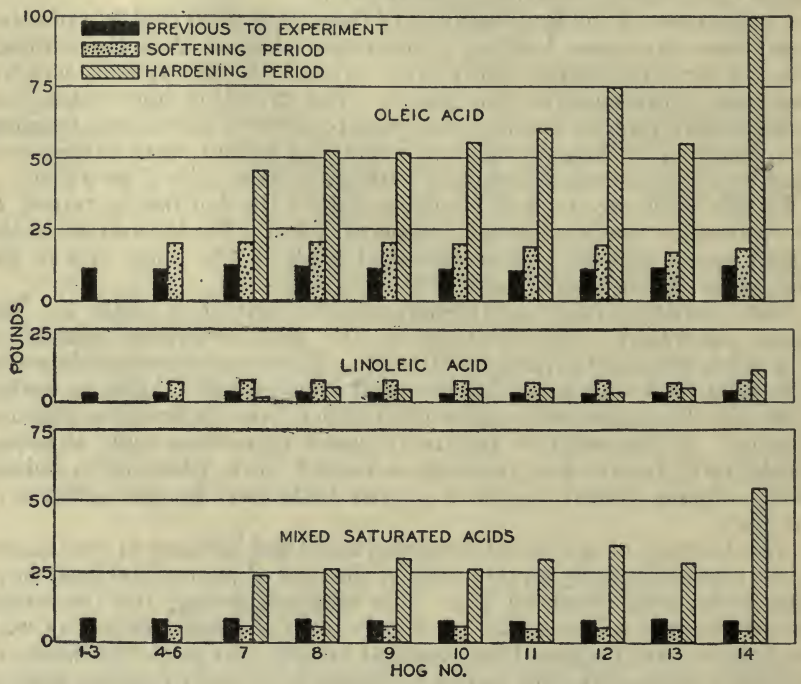

FIGURE 1.—Estimated increase in the principal fatty acids, by feeding periods, deposited in the adipose tissues of the hogs in lot A.

tion of hogs 4 to 14, with corrections for their weights, at the beginning of the peanut feeding. Then, from the difference in composition between the values for hogs 4, 5, and 6 and for hogs 1, 2, and 3 the actual quantity of total fat, as well as of the several fatty-acid fractions, deposited during the softening period was estimated. These calculations were then extended to the animals on the hardening ration. Similar methods were applied to lot B. The estimates for initial composition of the latter were made on the basis of data available in this laboratory for three hogs used in other experiments, as previously stated.

A comparison of gain ratios based on live weight and fat content for the hogs on the hardening rations is shown in table 5. The figures for lot A are in close agreement. Hog 13 was an exception. As already shown, this animal was unusually low in fat content at the time of slaughter and had evidently failed to fatten at the usual rate. The data on the other seven hogs in lot A indicate that the rate of fat

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storage remained rather constant during the experiment, with the result that the ratio of fat in gain increased in proportion to the increase in ratio of gain in live weight.

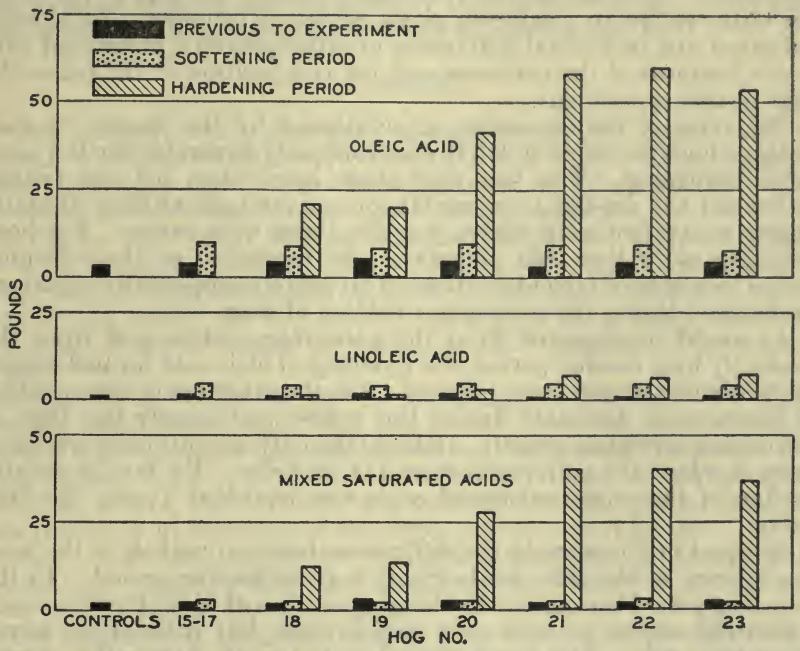

FIGURE 2.—Estimated increase in the principal fatty acids, by feeding periods, deposited in the adipose tissues of the hogs in lot B.

TABLE 5.—*Comparison of gain ratios based on gain in live weight and fat content*

LOT A (100 POUNDS INITIAL WEIGHT)

Hog no.	Ratio of softening gain to hardening gain based on—		Hog no.	Ratio of softening gain to hardening gain based on—	
	Gain in live weight	Weight of fat in gain		Gain in live weight	Weight of fat in gain
7	1:2.1	1:2.2	11	1:3.5	1:3.2
8	1:2.5	1:2.5	12	1:3.5	1:3.6
9	1:2.6	1:2.6	13	1:4.1	1:3.2
10	1:3.0	1:2.7	14	1:5.2	1:5.5

LOT B (40 POUNDS INITIAL WEIGHT)

18	1:2.0	1:2.1	21	1:4.7	1:6.3
19	1:2.1	1:2.2	22	1:4.4	1:6.1
20	1:2.9	1:3.8	23	1:5.1	1:6.2

A marked widening of the fat ratios with increasing gain ratios based on gain in live weight occurred in lot B. This is especially the case with hogs 21 and 22, in which the fat ratio was more than 1:6 for gain ratios of approximately 1:4.5. These findings indicate that dur-

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ing the period of growth when live weight was between 30 and 100 pounds the rate of fat storage per unit of live-weight increase on the softening ration was not so great as that later attained on the hardening ration. Such a condition materially lessens the gain required on the latter ration to produce a given degree of firmness. As already indicated, the individual differences in ratios played a prominent part in the firmness of the carcasses and the composition of the fat of the hogs in this experiment.

The rates of fat formation, as evidenced by the figures on gain ratios, which prevailed in lot B were especially favorable for the more rapid hardening. The fact that these hogs when fed the peanut ration did not deposit so much fat for a given gain as they did later during equivalent gain makes possible these wide ratios. For hogs weighing more than 100 pounds at the beginning of the softening period, the rate of fattening attained on peanuts apparently remained unchanged during the subsequent feeding of corn.

As would be expected from the percentage values and from the relatively long feeding period, the quantity of oleic acid formed during the hardening period is the greatest. On the other hand, the quantity of linoleic acid deposited during this period was usually less than in the earlier softening period. Indeed, the only exceptions were those cases in which the gain ratios were 1:4 or wider. By far the greater portion of the mixed saturated acids was deposited during the final period.

Of equal importance to the differences between periods is the relative storage of the fatty acids within a given feeding period. In the softening period the ingestion of large quantities of peanut oil furnished a plentiful source of oleic and linoleic acids but little of the mixed saturated acids. The fat deposited in the body during this period was similar in composition to that of the ingested oil. The linoleic acid ranked second in quantity to oleic acid. The hardening period brought a change in the proportions. In the synthesis of fat from carbohydrates the predominating fatty acids formed are oleic, palmitic, and stearic, in the order named. Thus, the chief difference between the two periods as to relative ranking lies in the replacement of linoleic acid by the mixed saturated acid group.

In the discussion of the composition of the fat, emphasis has been placed on the fatty acid distribution. These acids occur in the fat in various glyceride combinations. The many possible combinations of mixed glycerides, as well as simple glycerides, with wide range in melting points add complexity to the question of firmness of the fat. It is probable that the feeding of widely different feeds in successive periods produces a different series of glycerides from that which would be formed were the same materials fed together. Although no information on the glycerides as such is available on the samples studied, the foregoing should serve to indicate their influence on the firmness of the fat. Nevertheless, the fatty acid distribution remains of primary importance. In order to obtain even moderately firm body fat in hogs which have become soft, sufficient saturated acids must be added to offset the unsaturated acids.

From the data on composition of the hog carcasses as it relates to the changes in fat content and in the fatty acid composition of the body fat, it is evident that fat storage is an important factor in the

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hardening of peanut-fed hogs. In the usual hardening procedure the softening effects of the oily fat can be offset only by additional deposition of hard fat—that is, fat high in mixed saturated acids and low in unsaturated acids, particularly the linoleic—to the extent that the resulting mixture approaches that of normal firm fat.

SUMMARY

Two groups of hogs averaging approximately 100 pounds and 40 pounds in initial weights were compared in a study of the quantitative relationship of storage of fat to firmness as influenced by the use of peanuts and of corn in successive feeding periods.

A higher rate of fat storage prevailed during the period the hogs were on the peanut ration than when they were on the corn ration. The group of hogs which averaged 100 pounds at the beginning of the experiment stored the oily fat at a somewhat more rapid rate than the group which averaged 40 pounds at the beginning of the experiment.

Hogs which continued on the hardening ration until the gains reached multiples ranging from two to five times the amount stored on the softening ration generally showed increasing firmness. The gain in total fat was generally more closely related to firmness than the gain in live weight. For the same gain ratio, greater firmness was produced in the hogs in the lower initial weight group.

Analyses of fat samples showed marked decreases in saturation as a result of peanut feeding and an increase in saturation or firmness after the feeding of the corn ration.

The addition of hard fat, formed from the nonfatty constituents of the hardening ration, to the oily fat already formed during the peanut-feeding period produced a gradual hardening of the body fat as a whole. The group of saturated acids replaced linoleic as second to oleic acid when the corn ration was substituted for the peanut ration.

LITERATURE CITED

(1) Ellis, N. R., and Hankins, O. G.
1925. SOFT PORK STUDIES. I. FORMATION OF FAT IN THE PIG ON A RATION MODERATELY LOW IN FAT. Jour. Biol. Chem. 66:101–122, illus.

(2) ——— and Isbell, H. S.
1926. SOFT PORK STUDIES. II. THE INFLUENCE OF THE CHARACTER OF THE RATION UPON THE COMPOSITION OF THE BODY FAT OF HOGS. Jour. Biol. Chem. 69:219–238, illus.

(3) Halverson, J. O., Hostetler, E. H., and Sherwood, F. W.
1931. THE VALUE OF PEANUTS FOR GROWING PIGS. N.C. Agr. Expt. Sta. Tech. Bul. 41, 27 p., illus.

(4) Hankins, O. G., Ellis, N. R., and others.
1926. SOME RESULTS OF SOFT PORK INVESTIGATIONS. U.S. Dept. Agr. Bul. 1407, 68 p., illus.

(5) ——— Ellis, N. R., Zeller, J. H., and others.
1928. SOME RESULTS OF SOFT-PORK INVESTIGATIONS, II. U.S. Dept. Agr. Bul. 1492, 50 p., illus.

(6) ——— and Zeller, J. H.
1929. CORRECTING THE INEFFICIENCY OF PEANUTS FOR GROWTH IN PIGS. U.S. Dept. Agr. Tech. Bul. 110, 12 p., illus.

(7) Mohler, J. R.
1927. REPORT OF THE CHIEF OF THE BUREAU OF ANIMAL INDUSTRY. U.S. Dept. Agr. Ann. Rpt. 50 p.

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TECHNICAL BULLETIN No. 369 AUGUST 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

PIMA EGYPTIAN COTTON IN IRRIGATED ROTATIONS AT THE YUMA FIELD STATION, BARD, CALIF.

By STEPHEN H. HASTINGS, *principal agronomist*, and EDWARD G. NOBLE, *associate agronomist, Division of Western Irrigation Agriculture, Bureau of Plant Industry*

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INTRODUCTION [1]

Agronomic investigations on crop-production problems in the Yuma Valley have been conducted by the Department of Agriculture since 1906. Prior to that time some work had been done in that area, in cooperation with farmers, in testing and selecting varieties of forage crops and of Egyptian cotton. Until 1910 the investigational work was conducted in the lower valley on the Arizona side of the Colorado River, largely in the vicinity of Somerton. In 1910 a portion of the Indian reservation on the California side of the river, north of Yuma, was opened to settlement, and a tract of 160 acres of public land adjacent to the town site of Bard was allocated to the Bureau of Plant Industry for use as a field station. This station is now known as the United States Yuma Field Station.

When the station was established a keen interest in the possibilities and problems of cotton production was developing among the farmers of the Yuma Valley. Very little information was then available concerning cotton production under irrigation in the southwestern United States. Consequently much of the work at the new station was designed to obtain information most urgently needed by prospective cotton growers regarding types and varieties of cotton, methods of planting, irrigation, and tillage of the crop, and means of producing adequate supplies of seed for planting each year.

[1] By Carl S. Scofield, principal agriculturist in charge, Division of Western Irrigation Agriculture.

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It was immediately apparent that if cotton was to be profitable on the irrigated lands of the Yuma Valley where cost of production was relatively high, varieties and methods of production that would yield large returns must be adopted. During the early years, varieties selected locally from the product of seed imported from Egypt were produced to some extent. Then varieties of long-staple upland and finally short-staple varieties from Texas were grown. These upland varieties have yielded well in the Yuma Valley, and at the present time the acreage devoted to cotton is planted almost wholly to varieties of the short-staple upland type.

For the past 17 years a large proportion, often more than half, of the cropped acreage of the Yuma Valley has been planted to cotton. This has meant that some of the same land has been devoted to cotton for several successive seasons, with the result that the yields have declined. The desire to devote a large part of the acreage to cotton has been accompanied by demands for information about crop-rotation methods and fertilization that would best maintain the high cotton yields essential to profitable returns. The comprehensive series of rotation experiments described in this bulletin were begun in 1923 to meet this demand. The view then generally held was that cotton production was well established as a part of the agriculture of the irrigated lands of the Southwest and that cotton might long continue to be an important crop in that area. Consequently, the agronomic experiments herein described were carefully planned with the idea of continuing them for many years. It is well recognized that some of the information essential to intelligent planning of a continuing program of crop production can be obtained only from carefully planned field experiments that are consistently carried forward. It is believed that the experiments here described meet that requirement, and also that the program is sufficiently elastic to permit the inclusion of new questions that may arise from time to time.

When these experiments were started, one question that had to be decided was what variety of cotton to use. During the previous 10 years, which included the war period, the local farmers had successively grown varieties of long-staple Egyptian cotton, long-staple upland, and short-staple upland. At that time (1923) local opinion was divided as to which variety, or even which type, might be expected eventually to prove the most profitable. It was the writers' belief then, and still is, that one of the varieties of the Egyptian type of cotton will ultimately prove to be the most profitable for the Yuma Valley. Consequently, it was decided to use a variety of that type in these experiments. It is believed that, with respect to most of the fundamental agronomic questions which these experiments were designated to answer, the results would be substantially the same, no matter what variety of cotton was used, provided the same variety was used throughout the experiment. Because of price differences certain of the economic interpretations would be conditioned, of course, by the variety used.

It should be observed that the field plots involved in this experiment are located on land that has been deposited and worked over by flood waters of the Colorado River during comparatively recent times. In fact, the local topography is such that it was necessary, as part of the reclamation program, to construct a levee along the river

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to protect the area, which includes the field station, from the recurring floods. As a result of this mode of origin, the soil is extremely variable in texture and in natural productivity. This variation occurs not only between plots but also within the plots, and must be taken into account in considering the results of the cropping experiments. It is apparent that with the progress of time and the continuing use of silt-laden irrigation water there has been a marked improvement in the uniformity in the soil texture of the root zone.

The subsoil conditions of the area are such that there is free underdrainage into an intercommunicating underground "water table", and it has been possible to use irrigation water copiously without waterlogging the root zone. As a consequence, the experiment has not been complicated by the local accumulation of soluble salts even though the salt content of the irrigation supply averages slightly more than 1 ton of salts in each acre-foot of water. Furthermore, the proportions of the basic constituents of these salts have been such that the reactions of base exchange in the soil have not impaired its physical condition. It has continued for more than 20 years to absorb water readily, to leach freely, and to possess good tilth.

One other point deserves notice. The crop-rotation program of these experiments is largely built upon the use of alfalfa as a means of restoring or maintaining the fertility of the soil against the depleting action of such crops as cotton, barley, milo, and corn. Unfortunately, it has been observed that it has been increasingly difficult to establish alfalfa and to maintain it in vigorous growth in these experimental plots. This difficulty with alfalfa has not been limited to these plots nor to the field station, but is reported as occurring generally throughout the Yuma Valley. It is a condition that may have to be considered, not only in drawing conclusions from these rotation experiments but also in connection with the general agricultural situation in the valley.

SOIL

The United States Yuma Field Station is located at Bard, Calif., 8 miles northeast of Yuma, Ariz., about 2 miles from the northern edge of the Yuma reclamation project. The area represented by the Yuma reclamation project forms a part of the northeastern portion of the Colorado River delta. The valley soil is made up of sediments and consists of a great bed of sand overlain and interstratified with silt deposited by the river as it shifted its course from one side of the valley to the other. Throughout the project the surface soil ranges from a coarse sand to a fine silt and ranges in depth from a few inches to several feet. The subsoil underlying the valley surface soil is easily pervious to water, and since it lies close to the river channel the ground water is not far below the surface. At the station and on similar areas the level of the underground water fluctuates with the level of water in the river.

The irrigation water for the project is diverted from the Colorado River at the Laguna Dam. The stream at all times carries substantial quantities of silt, and after several years of irrigation the character of the surface soil changes materially, particularly the areas of a definitely sandy nature, because of the deposition of the fine silt by the irrigation water.

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The soils at the Yuma Field Station are well drained but somewhat variable in texture. At first the sandier land was not productive, but the deposits of silt brought in by irrigation water and the growing of soil-improvement crops such as alfalfa have improved its condition. At present the cotton yields obtained from the better rotations compare favorably with those from sections of the valley that were originally more productive.

CLIMATIC CONDITIONS

The arid climatic conditions which characterize the Yuma Valley are similar to those existing generally throughout the lower Colorado River Basin. The average annual rainfall of less than 4 inches is not a factor in crop production. Summer temperatures are relatively high and winter temperatures mild. The long frost-free summer period is favorable for the production of crops, such as cotton, which require a long growing season.

Meteorological records have been kept at the Yuma Field Station since April 1910. For the period 1910–30 the maximum temperature recorded was 120° F. in May 1910. The minimum temperature was 16° F. in December 1912 and again in January 1913. The frost-free period has averaged 259 days during 21 years. The average date of the last killing frost in the spring is March 6, and the average date for the first killing frost in the fall is November 20.

The rainfall records show that the average annual precipitation has been 3.95 inches. Most of this moisture has been the result of two or three general storms during the fall and winter months. Local thunder showers are occasional in July and August. The months of April, May, and June are normally very dry. Records on evaporation from a free-water surface show that the annual total for the 21-year period has averaged 73.1 inches per year.

In order that the information may be available relating to certain meteorological data for the 8-year period 1923–30, table 1 is included, giving monthly absolute maximum, mean maximum, mean minimum, and mean temperatures.

TABLE 1.—*Monthly absolute maximum, mean maximum, mean minimum, and mean temperature observations at the Yuma Field Station for the 8-year period 1923–30*

ABSOLUTE MAXIMUM TEMPERATURES (°F.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Maximum for year
1923	84.0	90.0	89.0	97.0	108.0	113.0	110.0	107.0	111.0	97.0	84.0	73.0	113.0
1924	77.0	86.0	85.0	91.5	106.5	113.0	111.0	110.0	110.0	107.0	99.0	82.0	113.0
1925	83.0	86.0	94.0	104.0	104.0	114.0	117.0	108.0	104.0	100.0	87.0	79.0	117.0
1926	76.0	87.0	91.0	100.0	104.0	113.0	109.0	111.0	105.0	102.0	93.0	80.0	113.0
1927	80.0	88.0	94.0	104.0	113.0	111.0	113.5	117.5	108.0	104.5	88.0	80.0	117.5
1928	84.0	83.0	97.0	97.0	106.5	112.0	115.0	115.0	114.0	103.0	89.0	78.0	115.0
1929	78.0	86.0	93.5	94.5	102.0	116.0	113.0	114.5	111.5	106.5	89.0	83.0	116.0
1930	76.0	90.0	92.0	103.0	103.0	112.0	114.0	114.0	110.0	98.0	93.0	77.0	114.0
Maximum for month	84.0	90.0	97.0	104.0	113.0	116.0	117.0	117.5	114.0	107.0	99.0	83.0	117.5

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TABLE 1.—*Monthly absolute maximum, mean maximum, mean minimum and mean temperature observations, etc.*—Continued

MEAN MAXIMUM TEMPERATURES (°F.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1923	73.3	72.7	76.9	83.2	96.1	96.9	103.0	103.7	96.8	87.7	77.6	66.1	86.2
1924	67.5	78.7	75.6	79.6	93.4	105.0	104.9	104.5	101.9	89.6	81.7	68.7	87.6
1925	68.4	78.7	82.0	87.4	95.9	100.2	106.6	104.0	99.7	84.0	75.9	70.7	87.8
1926	68.3	77.2	81.5	87.3	93.7	104.0	105.5	104.4	100.3	93.8	82.9	65.1	88.7
1927	70.9	75.8	78.4	87.2	95.8	101.2	106.6	104.8	99.8	92.8	79.7	66.4	88.3
1928	71.6	74.2	82.6	86.9	94.9	101.8	106.4	104.5	104.2	92.2	78.4	68.6	88.9
1929	67.2	70.9	79.1	83.3	96.1	101.8	106.4	104.8	98.4	93.7	78.1	76.3	88.0
1930	66.1	80.2	78.9	89.6	87.9	102.3	106.6	104.9	99.5	89.0	80.0	69.0	87.8
Average	69.2	76.1	79.4	85.6	94.2	101.7	105.8	104.5	100.1	90.4	79.3	68.9	87.9

MEAN MINIMUM TEMPERATURES (°F.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1923	39.2	41.1	41.5	48.9	57.0	56.1	71.4	70.7	62.4	48.0	46.1	41.7	52.0
1924	34.7	39.5	39.7	45.4	54.8	63.9	69.7	67.3	63.9	45.3	41.9	38.8	50.4
1925	33.1	39.5	43.7	47.5	56.9	63.4	73.2	70.9	59.3	51.9	40.8	39.4	51.6
1926	33.2	41.4	46.8	53.7	55.0	62.4	70.3	70.3	65.6	52.3	42.1	38.2	52.6
1927	39.5	44.4	40.9	46.7	52.8	60.9	72.3	73.2	63.3	51.4	46.2	37.7	52.4
1928	37.2	38.1	44.1	46.1	57.2	60.9	68.3	71.2	63.0	51.6	43.0	38.9	51.6
1929	32.1	36.0	42.5	45.3	54.2	60.7	73.4	75.4	66.1	54.2	40.0	38.9	51.6
1930	37.8	42.9	46.3	52.6	51.5	60.5	73.4	70.3	60.8	48.9	44.2	34.5	52.0
Average	35.9	40.4	43.2	48.3	54.9	61.1	71.5	71.2	63.1	50.5	43.0	38.5	51.8

MEAN TEMPERATURES (°F.)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1923	56.2	56.9	59.2	65.9	75.7	76.4	88.6	87.1	79.4	67.8	62.0	53.5	69.1
1924	52.3	57.0	57.0	63.4	70.7	84.4	87.2	85.9	82.9	67.4	61.3	51.6	68.4
1925	50.8	59.1	62.9	67.8	76.4	81.8	89.9	87.5	79.5	68.2	58.4	55.1	69.8
1926	50.7	59.3	64.1	70.5	74.3	82.7	87.9	87.3	82.9	73.0	62.5	51.6	70.6
1927	55.2	60.1	59.7	66.9	74.3	81.1	89.5	89.0	81.6	72.1	62.9	52.1	70.4
1928	54.4	56.2	63.4	66.7	71.1	81.4	87.4	87.9	83.6	71.9	60.7	53.8	69.9
1929	49.7	53.5	60.8	64.3	75.2	81.3	89.9	89.8	82.5	74.2	57.2	57.8	69.7
1930	51.9	61.6	62.6	71.1	69.7	81.4	90.0	87.6	80.1	69.2	62.0	52.0	69.9
Average	52.7	58.0	61.2	67.1	73.4	81.3	88.8	87.8	81.6	70.5	60.9	53.4	69.7

CULTURAL PRACTICES

The climatic conditions in the area represented by the Yuma project are such that by the selection of crops which will withstand the winter temperatures, crop growth is continuous throughout the year. Such hardy crops as the cereals, vetch, and sour clover (*Melilotus indica*) are fall planted and make some growth even during the winter months, and if temperatures are mild the growth is substantial. The planting dates of the summer crops which will not survive the winter temperatures range from early March to midsummer. The harvesting periods are correspondingly extended. Cotton is usually planted about March 15, and harvesting extends from early in September to December. The grain sorghums and corn are planted in late June or early July and are ready to harvest the latter part of October.

Alfalfa may be planted from early in October until the middle of February. The first hay crop is harvested the latter part of March or early in April, and the last crop in the fall is harvested late in November or early in December. Some growth is made during the winter months, which is often pastured. When a seed crop of alfalfa is to be harvested, usually one cutting of hay is made, and the growth thereafter is permitted to set seed, which matures early in July. It has been the custom to apply commercial fertilizer in the form of

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superphosphate to the plots in alfalfa. The application is made in the spring, immediately after the first hay crop is harvested (*14*).[2]

In the experiments described in this bulletin where alfalfa follows cotton or grain sorghum, the plots were seeded the latter part of December or early in January. Sweetclover (*Melilotus alba*) is similarly treated. As barley is grown exclusively as a winter crop, it is planted as soon after November 1 as possible. When preceded by cotton or grain sorghum, it is planted the latter part of December. Barley is harvested late in April or early in May. Sour clover and vetch (*Vicia calcarata*), which are included in the series for the purpose of ascertaining their value as green-manure crops, are planted in the fall, preferably early in October. When cotton is the preceding crop, the sour-clover and vetch seed are broadcast in the standing cotton stalks just prior to the last fall irrigation. Both of these crops are plowed under shortly before the land is prepared for cotton.

In one 2-year rotation (no. 22) Victor cowpeas (*Vigna sinensis*) are used as a green-manure crop. The cowpeas are disked in the cotton stubble about April 1 and the subsequent growth plowed under late in June, preparatory to planting grain sorghum. Sweetclover is used in four rotations for soil-improvement purposes. Where this crop follows cotton and precedes sorghum, as in rotations 20 and 30, the sweetclover seed is disked in the cotton stubble and the growth plowed under prior to preparing the land for the sorghum crop. The period of growth for sweetclover under these conditions is from the latter part of December to the latter part of June. It will be observed that sweetclover appears twice during the cycle of rotation 30. In the second instance the clover is seeded with barley late in December, the barley is harvested early in May, and the sweetclover growth is plowed under the following June before the corn is planted. Sweetclover also appears in rotation 54, and the same procedure is followed, except that grain sorghum is substituted for corn. The practice followed in rotation 36 is to seed sweetclover in the cotton stubble in the late fall, taking advantage of the growth made throughout the following summer. The crop is harvested for seed, and the land is plowed in the fall, preparatory to planting cotton the following spring.

The land is plowed to a depth of about 8 inches, disked when necessary, and well leveled in order that irrigation water may be uniformly applied. Preparatory to planting, the land is thoroughly irrigated. As soon as the surface soil is in proper condition to work, it is gone over twice with a spike-tooth harrow, which operation in most instances is sufficient to provide a satisfactory seed bed. However, where there is some turf in the plowed land it may be necessary to work the ground with a disk harrow.

Cotton is planted in rows 42 inches apart, with a standard 2-row press-wheel cotton planter. A furrow opener attached to each shoe to insure a uniform depth of planting is recommended (*6*). About 50 pounds of seed is planted per acre, which is far in excess of the amount ordinarily used. Weather conditions are frequently unfavorable following planting, and by seeding heavily it has been found that the hazards of obtaining a good stand are greatly reduced.

The first cultivation is given as soon as the cotton is up and the rows are well defined. Subsequent cultivations are as frequent as is

[2] Italic numbers in parentheses refer to Literature Cited, p. 30.

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found necessary to maintain a soil mulch and to keep the land free from weeds. Cultivation is continued throughout the growing season or until the plants are so large that there is danger of injury by the operation. Shovel attachments are used when the plants are small, but as they become larger disk attachments are employed, and the soil is worked toward the plants, with the result that well-defined furrows are formed between the rows.

SPACING THE PLANTS

For the first 2 years, 1923 and 1924, the plants were thinned so as to be spaced 14 inches apart in the row. Subsequently on one half of each plot the aim has been to have a plant every 7 inches and on the other half every 14 inches, for the purpose of ascertaining to what extent yields may be influenced by these two different spacing distances. Moderately delayed thinning has been practiced, partly to permit the plants to become well established and also to encourage early fruiting and the suppression of vegetative branches and thereby avoid excessive vegetative plant growth which may occur at the expense of fruit (*5*). During the thinning operation the soil is removed from around many of the plants; consequently, it has been found desirable to cultivate immediately after the cotton is thinned, throwing as much soil to the plants as their size will permit.

IRRIGATION

Ordinarily, cotton does not need an irrigation after the one given before planting until it has been cultivated two or three times, or well into May. As a rule the first irrigation after planting is not given until the plants begin to show need of moisture. The second irrigation is withheld until the plants begin to form fruiting buds freely, usually after an interval of about 3 weeks. It has been customary to give the third irrigation when there is a definite tendency toward profuse flowering, which is usually about 2 weeks later. Thereafter and during the height of the fruiting season the plots are watered regularly each week. As the temperatures begin to moderate in the fall, irrigations are given less frequently, but sufficient moisture has been maintained in the soil to meet adequately the needs of the plants so that the crop may mature properly.

The amount of water required to mature a crop of cotton under these conditions is estimated as 5½ acre-feet. Undue economy in the use of water is avoided. Light irrigations are not resorted to, and throughout the growing and maturing season of the cotton crop it is highly probable that at times some of the water applied is lost by passing downward through the root zone into the water table, several feet below the surface. Such a condition has been recognized as advantageous rather than harmful. The Colorado River water diverted for use on the Yuma project carries a salt burden of approximately 750 parts per million, or about 1 ton of salt per acre-foot; and if the root zone is not leached periodically, it is evident that the productivity of the soil will eventually become seriously impaired. It is believed that an important contributing factor in obtaining yields of almost a bale an acre, recorded in these investigations from the better rotations, has been the copious use of irrigation water to avoid the harmful concentration of salt in the soil solution (*7*).

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HARVESTING

Although a few cotton bolls begin to open in late July, the first picking is usually delayed until about October 1. It has been the practice to go over the plots but twice, the second or last picking taking place shortly after the first killing frost. The yields from individual rows are harvested and weighed separately, and the totals are compiled to obtain the recorded yields in pounds of seed cotton per acre.

If it is desired to determine the approximate number of pounds of lint, such a figure may be obtained by assuming a lint outturn of 26 percent, the figure commonly adopted in the Salt River Valley of Arizona and found to be representative over a period of years. There is no available evidence to indicate that the lint percentage of Pima cotton produced in the Yuma Valley differs materially from that found in the Salt River Valley, which has been the center of the Pima industry in the Southwest. By using this factor of 26 percent lint, it is possible for the reader to convert the seed-cotton yields into pounds of lint. This is the procedure that has been used in a few instances in the following pages.

OBJECT OF THE ROTATIONS

For the past 15 years more than half of the cultivated land on the Yuma reclamation project has been devoted to the production of cotton. After a few years it became evident that information was needed as to the cropping system or systems most likely to maintain and improve yields. It was proposed to obtain this information at the Yuma Field Station by using as a basis continuously cropped plots, the yields from which were to be compared with those obtained from various crop sequences with barley, grain sorghum, corn, and alfalfa. In the case of continuous cropping, 6 plots were used, one of which was untreated, and the others included certain legumes, applications of complete fertilizers, and stable manure. As the winter temperatures are so mild that certain of the hardy crops are fall planted and make some growth during the winter, in outlining the different cropping systems hardy winter legumes such as vetch and sour clover were included in some cases to ascertain their effect on the yields of cotton. The value of stable manure is tested in a number of cropping systems, and in two rotations the effect of harvesting alfalfa with livestock is investigated.

Usually the harvesting of cotton is completed in December, and as barley is grown only as a winter crop in this section it may be planted immediately and is harvested in late April or early May. It is customary to plant such crops as grain sorghum and corn early in July, and they mature in late October. Thus it is possible to grow three major crops, one of which is cotton, in two years. The continuous growing season permits of heavy cropping of the land, such as occurs in rotation 31, in which five major crops are harvested during the 3-year cycle of the rotation.

An effort was made to ascertain which cropping methods, crop treatments, and rotations would result in large yields of cotton by (1) comparing the yields of the continuously cropped plots variously treated with those in a rotation of two or more years; (2) noting the effect on yields when alfalfa, barley, corn, and grain sorghum im-

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mediately precede cotton; (3) ascertaining to what extent yields of cotton are influenced by the inclusion of certain annual legumes in various cropping systems; (4) determining the influence on yields of cotton when alfalfa is grown 2 years as compared with 3 years; (5) comparing first-year yields of cotton with those obtained the second and third season, since in certain rotations cotton is grown 2 years and, in the case of no. 64, 3 years in succession; and (6) determining the influence on yields of 1 year of summer-fallow as compared with more intensive cropping systems.

The original series of 16 rotations which included cotton became part of the investigational program of the station in 1923. In 1928 nine additional rotations were added to the series, making a total of 25 in all. The first series were located in the north part of fields C and D. Those included in 1928 were in the same fields but immediately south of the 1923 series.

In the first series of Pima-cotton rotations, started in 1923, the following treatments and crop sequences were included:

Cotton grown continuously on the same land each year: No. 4, cotton (400 pounds of complete fertilizer is applied in alternate odd years; i.e., 1923, 1925, 1927, etc.); no. 5, cotton (12 tons of stable manure applied in alternate odd years as in no. 4); no. 6, cotton (untreated); no. 7, cotton and vetch.

The 2-year rotations were as follows: No. 20, cotton (sweetclover), grain sorghum (vetch); no. 22, cotton (cowpeas), grain sorghum; no. 23, cotton, grain sorghum (manure).

There was only one 3-year rotation in this series: No. 30, cotton (sweetclover), grain sorghum, barley (sweetclover), and corn.

The following are 4-year rotations that include alfalfa: No. 40, cotton, cotton, alfalfa, alfalfa-corn (300 pounds of superphosphate is applied each year to alfalfa (second-year alfalfa is plowed in June); no. 44, cotton, cotton, alfalfa, alfalfa (300 pounds of superphosphate is applied each year to the alfalfa); no. 46, cotton, alfalfa, alfalfa (300 pounds of superphosphate is applied each year to the alfalfa), barley-grain sorghum.

The 5-year rotations consisted of two: No. 50, cotton, alfalfa, alfalfa, alfalfa (300 pounds of superphosphate to be applied each year to the alfalfa), barley-grain sorghum; no. 52, cotton, alfalfa, alfalfa, alfalfa (300 pounds of superphosphate is applied to the alfalfa each year; third-year alfalfa is plowed in June); grain sorghum.

There were three 6-year rotations with crop sequences and treatments as follows: No. 60, cotton, cotton, alfalfa, alfalfa, alfalfa (300 pounds of superphosphate is applied to the alfalfa each year), barley-grain sorghum; no. 61, cotton, cotton, grain sorghum, alfalfa, alfalfa, alfalfa (harvested by hogs the third season); no. 63, cotton, cotton, barley-alfalfa, alfalfa, alfalfa (harvested by hogs the third season, March to July), alfalfa-corn.

Nine additional cropping systems were added to the series in 1928 in order to develop further information. These included, among others, two continuously cropped plots with a view to determining to what extent yields could be maintained or improved by applying superphosphate in conjunction with sour clover and vetch.

Continuously cropped: No. 7a, cotton (vetch, 300 pounds per acre annually of superphosphate, is applied before spring plowing); no. 7b, cotton (sour clover, 300 pounds per acre annually of superphosphate, is applied just before spring plowing).

The 3-year rotations added to the series at this time were: No. 31, cotton, barley (manure)–grain sorghum, barley-grain sorghum (manure); no. 34, cotton, cotton, fallow; no. 36, cotton, cotton, sweetclover.

The 5-year rotations included were: No. 54, cotton, cotton, barley-grain sorghum (sweetclover seeded in with barley and plowed under after the barley is harvested in June, preparatory to planting the sorghum), alfalfa, alfalfa (300 pounds of superphosphate is applied to the alfalfa each year); no. 56, cotton, barley-grain sorghum, alfalfa (500 pounds of superphosphate is applied to the alfalfa after the

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first hay crop is removed), alfalfa, alfalfa (one crop of seed harvested each, the second and third years).

Two 6-year rotations were also added, as follows: No. 64, cotton, cotton, cotton, alfalfa, alfalfa (first and second year, 300 pounds of superphosphate is applied), alfalfa (one crop of seed harvested in the third year); no. 65, cotton, cotton, barley (manure)–grain sorghum, alfalfa, alfalfa (500 pounds of superphosphate is applied the first and second years), alfalfa–grain sorghum (alfalfa plowed under in June).

In listing certain crops in the various rotations it will be observed that a short dash is used to separate the words, as, for instance, barley–grain sorghum, and alfalfa–grain sorghum in rotation 65. This signifies that both barley and grain sorghum were harvested in one calendar year. In the case of alfalfa–grain sorghum it implies that alfalfa occupied the land until June, when the land was plowed for grain sorghum, which is planted in July. When the designation is barley–alfalfa, as in rotation 63, the implication is that the alfalfa is seeded in with the barley in the fall or early winter.

In planning these rotations the arrangement was such that while there were not always so many years as there were major crops in the rotation, yet the cropping system was so outlined that each of the crops appeared at least once annually. Such a condition existed because in certain rotations comparable to no. 30 two major crops were harvested the same season. By this method it is possible to compare the yields of cotton as well as those obtained from other crops from each of the rotations each year.

LIST OF ROTATIONS

For convenient reference, the following list of the various rotations which include cotton is given. Those not included in this series until 1928 are designated by that year. In those rotations receiving treatments of manure or commercial fertilizers the pounds or tons given show the rate per acre at which they were applied.

COTTON CONTINUOUSLY

4. Cotton with 500 pounds of complete fertilizer applied in alternate odd years.
5. Cotton with 12 tons of stable manure applied in alternate odd years.
6. Cotton untreated.
7. Cotton with vetch.

7a. Cotton with vetch, 300 pounds of superphosphate applied before plowing under vetch. Started in 1928.

7b. Cotton with sour clover, 300 pounds of superphosphate applied before plowing under clover. Started in 1928.

TWO-YEAR ROTATIONS

20. Cotton with sweetclover, grain sorghum with vetch.
22. Cotton with cowpeas, grain sorghum.
23. Cotton, grain sorghum with manure.

THREE-YEAR ROTATIONS

30. Cotton with sweetclover, grain sorghum, barley with sweetclover, corn.
31. Cotton, barley (manure), grain sorghum, barley, grain sorghum (manure). Started in 1928.
34. Cotton (first year), cotton (second year), fallow. Started in 1928.
36. Cotton (first year), cotton (second year), sweetclover. Started in 1928.

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FOUR-YEAR ROTATIONS

40. Cotton (first year), cotton (second year), alfalfa [3] (1½ years), corn.
44. Cotton (first year), cotton (second year), alfalfa [3] (2 years).
46. Cotton alfalfa [3] (2 years), barley, grain sorghum.

FIVE-YEAR ROTATIONS

50. Cotton, alfalfa [3] (3 years), barley, grain sorghum.
52. Cotton, alfalfa [3] (3½ years), grain sorghum.
54. Cotton (first year), cotton (second year), barley (sweetclover), grain sorghum, alfalfa [4] (2 years). Started in 1928.
56. Cotton, barley, grain sorghum, alfalfa [3] (2 years). Started in 1928.

SIX-YEAR ROTATION

60. Cotton (first year), cotton (second year), alfalfa [3] (3 years), barley, grain sorghum.
61. Cotton (first year), cotton (second year), grain sorghum, alfalfa (3 years, harvested with hogs the third season).
63. Cotton, cotton, barley-alfalfa,[3] alfalfa,[3] alfalfa (2½ years, harvested with hogs March to July), alfalfa-corn.
64. Cotton, cotton, cotton-alfalfa [3] (2 years), alfalfa (harvested for seed). Started in 1928.
65. Cotton, cotton, barley (manure), grain sorghum, alfalfa [5] (2½ years), grain sorghum. Started in 1928.

The location of the various rotations is shown in figure 1.

DETAILED YIELDS

In recording the cotton yields from these irrigated rotations it has seemed advisable to tabulate in detail the yields obtained throughout the 8-year period from each of the different cropping systems. There are a number of advantages to be derived from this method of presentation. The yearly fluctuation in yields may be observed, individually as to the different rotations and summarized for all rotations. It permits comparison of results obtained in a number of ways not followed in this discussion.

Detailed facts are presented in table 2, which gives the annual yields for the eight years from the 16 rotations begun in 1923. It will be observed that the yields have fluctuated; these fluctuations could not be attributed in all instances to the treatments the cotton received, and at times this has tended to distort the results. Fluctuations have been due in part to soil variation, and recently nematode injury is believed to have depressed yields somewhat. This latter factor appeared to be confined largely to the area occupied by rotations 20, 22, 23, 30, and 46, where definite indications of injury were apparent in 1931. In many cases, however, the cause or causes of yield fluctuations have not been clear. The variation in climatic conditions has also influenced yields, but usually, it is believed, fairly uniformly on all the cotton plots each season. The average of the annual yields is believed to reflect more accurately the differences which may be attributed to the various treatments and crop sequences. Consequently, 4-year mean yields have been computed representing the periods 1923–26 and 1927–30 and are tabulated in the last two columns of table 2. By comparing the two periods it is possible to observe the trends in yields.

[3] Three hundred pounds per acre of superphosphate applied annually to the alfalfa.
[4] Five hundred pounds per acre of superphosphate applied in the first season only.
[5] Five hundred pounds per acre of superphosphate applied at the beginning of the first two seasons only

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TABLE 2.—*Acre yield of Pima seed cotton (pounds) from the irrigated rotations at the Yuma Field Station, 1923–30*

Rotation no.	1923	1924	1925	1926	1927	1928	1929	1930	Mean, 1923–26	Mean, 1927–30	Percent mean 1927–30 is of mean of 1923–26
4	764	784	1,272	1,674	1,038	1,272	1,058	1,216	1,124	1,146	102.0
5	1,252	956	2,552	2,428	1,722	1,804	2,040	2,092	1,797	1,915	106.6
6	728	800	996	1,470	734	1,188	918	1,384	999	1,056	105.7
7	744	600	1,016	1,440	778	1,124	1,180	1,464	950	1,137	119.7
20	644	824	1,964	1,278	1,586	720	1,642	1,068	1,178	1,254	106.4
22	636	592	1,144	1,076	850	688	1,154	832	862	881	102.2
23	844	1,032	1,416	1,900	1,172	1,188	1,206	1,256	1,298	1,206	92.9
30	456	280	1,032	1,044	664	988	696	612	703	740	105.3
40-1	884	784	2,596	2,758	1,146	872	1,940	2,420	1,756	1,595	90.8
40-2	772	520	852	2,359	1,504	944	1,038	2,064	1,126	1,388	123.3
44-1	1,008	2,136	1,848	1,979	1,624	2,136	1,512	1,692	1,743	1,741	99.9
44-2	980	984	2,268	1,624	1,056	1,044	1,830	1,328	1,464	1,315	89.8
46	1,244	1,144	1,104	1,992	1,614	1,260	1,114	1,804	1,371	1,448	105.6
50	728	672	1,116	1,460	840	1,192	1,352	1,576	994	1,240	124.7
52	684	808	2,680	1,846	922	1,100	1,450	2,212	1,505	1,421	94.4
60-1	688	904	1,100	1,717	1,466	1,164	1,144	1,628	1,102	1,351	122.5
60-2	420	600	948	1,554	842	1,424	1,042	1,580	881	1,222	138.7
61-1	672	832	1,632	2,044	2,026	1,876	1,722	1,740	1,295	1,841	142.2
61-2	792	708	984	1,462	1,160	1,940	1,602	1,732	987	1,609	163.0
63-1	1,064	1,948	1,660	2,490	1,864	1,584	1,436	2,220	1,791	1,776	99.2
63-2	732	1,072	1,620	1,790	1,280	1,620	1,632	1,972	1,304	1,626	124.7
Annual mean	797	904	1,514	1,780	1,233	1,292	1,367	1,615	1,249	1,377	110.2

In presenting table 2 and other tables, recording yield data covering a period limited to 8 years and under soil conditions somewhat variable and unproductive, it is recognized that statistically only general conclusions may be safely drawn. Had it been practicable at the time these experiments were inaugurated to include a number of replications of each cropping system or had the period covered been materially extended, the resulting data would now be of such nature that more precise conclusions could be drawn. However, it is apparent from these results and from the field observations made throughout the 8 years that the different cropping systems have had a profound effect on crop yields, in certain instances favorable and in others distinctly unfavorable. From the information contained in these tabulated results and in the discussions which accompany them it is possible for those interested in cotton production in the Yuma Valley and in sections with comparable climatic and soil conditions to select a cropping system which will insure cotton yields materially in excess of those customarily harvested. Conversely, evidence is made available as to the adverse effect on cotton yields in certain rotations where the cropping system does not improve or even sustain the productivity of the soil.

Comparing the mean annual yields from all rotations, the highest was in 1926 when 1,780 pounds of seed cotton per acre was harvested, and the lowest was in 1923, the year the rotations were started, when only 797 pounds was harvested. The lowest individual yield was from rotation 30 in 1924, only 280 pounds per acre. The largest yield of seed cotton harvested from any of the rotations was 2,758 pounds per acre from rotation 40–1 in 1926. Assuming a lint percentage of 26 percent, this would indicate a net yield of 717 pounds of lint per acre.

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The highest yield from any cropping system, when summarized by periods, is that from the continuously cropped plot 5, which has had a biennial application of manure. This plot produced a mean yield for the period 1927–30 of 1,915 pounds of seed cotton, equivalent to 498 pounds of lint per acre. The lowest yield for both periods was

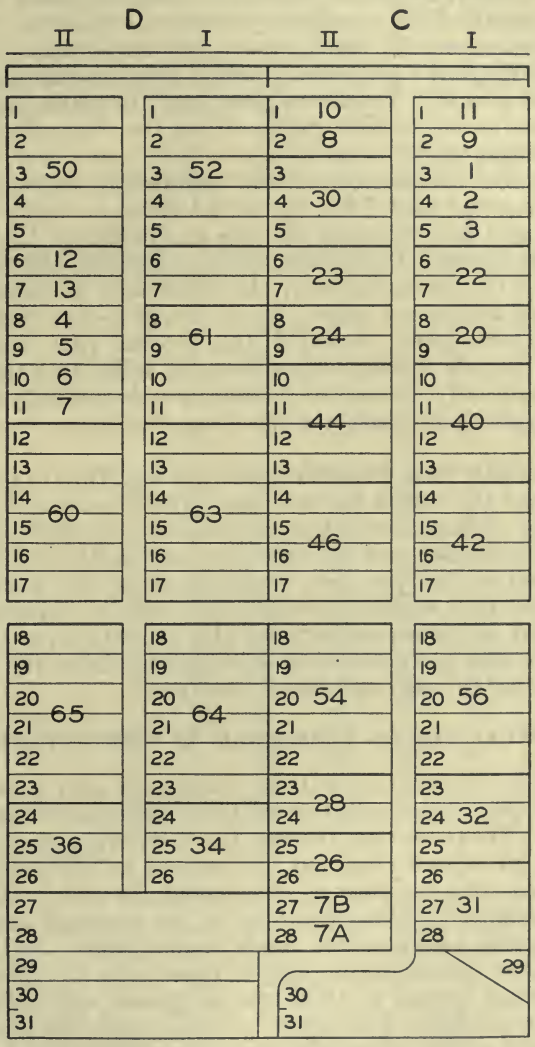

FIGURE 1.—Location of the irrigated rotations in fields C and D, Yuma Field Station.

from rotation 30, from which only 703 pounds per acre of seed cotton was harvested for the first 4-year period and 740 pounds for the second 4-year period.

In five of the rotations listed in table 2, two crops of cotton were harvested during the cycle. In alfalfa rotation 40, no. 40–1 is the first year of cotton following alfalfa, and no. 40–2 the second year the same plot is in cotton. Thus it is possible to observe how the

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second-year cotton yields are being sustained under the varying conditions of treatment.

The manure applied in odd years to continuously cropped plot 5 and the complete fertilizer applied similarly to plot 4, continuously cropped, afford an opportunity of comparing the yields of cotton obtained for the years these treatments were applied as compared with those obtained the years they were not treated. In order to compensate for seasonal variations, this comparison is based upon the results throughout the 8-year period from continuously cropped but untreated plot 6. These computations are made by ascertaining the differences in the annual yields of the two treated plots 4 and 5 and untreated plot 6.

Averaging the summation of the differences between untreated plot 6 and manured plot 5 for the 4 odd years in which manure was applied, this plot has exceeded the one untreated by 1,048 pounds of seed cotton per acre. Computing and comparing the yields for the even years in the same manner, the difference is found to be 610 pounds of seed cotton per acre. Thus, the first-year yields of cotton following manure have exceeded the second year and untreated years by 438 pounds of seed cotton per acre, indicating that if manure was applied annually instead of biennially substantially larger yields could be expected, at least for the years when no treatment was applied.

When the results from fertilized plot 4 are analyzed in the same way, it is found that the yields for the years when treatment was applied exceeded those obtained from the continuously cropped and untreated plot 6 by 189 pounds and for the even and untreated years by 26 pounds of seed cotton per acre, a difference of 163 pounds. These results indicate that while 500 pounds per acre of complete fertilizer has stimulated yields somewhat, yet the benefits, in the form of increased yields that have occurred immediately following application, are not appreciably apparent the second year.

ANNUAL YIELDS EXPRESSED AS PERCENTAGES

The yields of cotton have been computed and expressed as a percentage of the annual mean yields from all the rotations each year. This method affords an opportunity for comparing more readily the results which have been obtained with cotton in the various cropping systems. Also, this manner of comparing the results compensates in a large measure for the variations in the seasonal conditions, for by comparing the mean annual yields it is apparent that some years have been more favorable for cotton than others. This is evident when the annual means of 1926 are compared with those of 1927. The mean annual yield of all plots for 1926 was 1,780 pounds of seed cotton per acre, which obviously was a favorable year for relatively high yields. The mean yield for 1927 was only 1,233 pounds, a difference of 547 pounds of seed cotton per acre in favor of 1926. Hence, if the plot yields of 1926 are compared with those of 1927, with no consideration given to the influence of climate on yields, a correct analysis of the differences in yields of the different cropping systems is not possible. This may be illustrated by observing the differences in the yields of the continuously cropped and manured plot 5 for these 2 years. The yield from this plot in 1926 was 2,428

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pounds of seed cotton per acre, whereas in 1927 the yield was 1,722 pounds, or a difference of over 700 pounds per acre. If yields alone were considered, this would indicate that the yields from this plot were declining. However, when allowance is made for seasonal variations and the results of the 2 years for this plot are expressed in percentages of the means of all plots for the 2 years individually, the percentage is slightly more favorable for 1927 than it is for 1926. It is obvious that these percentage figures more nearly reflect the true conditions as they have existed during the 8 years on this cropping system as well as the others, the results of which are recorded in table 2.

The yields from the different cropping systems, computed on the basis of percentages of the annual mean yields, are presented in table 3.

TABLE 3.—*Annual acre yields of Pima seed cotton expressed as percentage of annual mean yields from all rotations for each year, at the Yuma Field Station, 1923–30*

Rotation no.	1923	1924	1925	1926	1927	1928	1929	1930	Mean, 1923–30[1]
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Annual mean	797	904	1,514	1,780	1,233	1,292	1,367	1,615	1,313
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
4	96	87	84	94	84	98	77	75	87
5	157	106	169	136	140	140	149	130	141
6	91	88	66	83	60	92	67	86	79
7	93	66	67	81	63	87	86	91	79
20	81	91	130	72	129	56	120	66	93
22	80	65	76	60	69	53	84	52	67
23	106	114	94	107	95	92	88	78	97
30	57	31	68	59	54	76	51	38	54
40–1	111	87	171	155	93	67	142	150	122
40–2	97	58	56	133	122	73	76	128	93
44–1	126	236	122	111	132	165	111	105	139
44–2	123	109	150	91	86	81	134	82	107
46	156	127	73	112	131	98	81	112	111
50	91	74	74	82	68	92	99	98	85
52	86	89	177	104	75	85	106	137	107
60–1	86	100	73	96	119	90	84	101	94
60–2	53	66	63	87	68	110	76	98	78
61–1	84	92	108	115	164	145	126	108	118
61–2	99	78	65	82	94	150	117	107	99
63–1	134	215	110	140	151	123	105	137	139
63–2	92	119	107	101	104	125	119	122	111

[1] Based on yearly percentages.

The highest mean percentage, 141, for the 8 years is that from plot 5, which was continuously cropped and manured; and the lowest percentage, 54, is from rotation 30. Rotations 4, 6, 7, 22, 30, and 50 at no time during the 8 years reached 100; and rotations 5, 44–1, and 63–1 did not fall as low as 100 during the period. The highest individual percentage is 236, from rotation 44–1 in 1924; and the lowest is 31, from rotation 30 the same year.

SUMMARIZED EFFECTS OF ROTATIONS ON YIELDS OF COTTON

In planning these rotations it was recognized that per acre cost of land preparation, irrigation water, and other fixed charges such as taxes and interest on capital, impose production costs on irrigated lands in excess of those incurred elsewhere. Under such conditions it is essential that the cropping system be conducive to large yields

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and that a substantial proportion of each farm unit be devoted to crops likely to yield adequate net returns on the farming enterprise as a whole. Unless information relative to these subjects is available and is used by the farmers, irrigated agriculture is not likely to be permanently successful.

In the production of staple farm crops, crop rotation has long been recognized as essential to sustained productivity of the land. Under certain favorable conditions as to land treatment, and particularly if stable manure is applied frequently, it has been demonstrated that for a few years the rotation of crops often may be disregarded without impairing yields. Unfortunately, however, stable manure is not always available. Such a condition exists on the Yuma project. The most satisfactory substitute for the manurial treatment is a well-planned rotation, which usually should include a leguminous crop such as alfalfa.

The results obtained from the different cropping systems and treatments and the more outstanding differences shown in the following discussion are summarized in table 4.

TABLE 4.—*Summary of the average yields of Pima seed cotton at the Yuma Field Station, 1923–30*

Rotation	Crops in the rotation		Average acre yields of Pima seed cotton	
			1923–26	1927–30
Continuous cropping:			*Pounds*	*Pounds*
6, untreated	Cotton		999	1,056
4, commercial fertilizer.	Cotton (400 pounds complete fertilizer applied in alternate years).		1,124	1,146
5, manured	Cotton (manured alternate years)		1,797	1,915
7, winter vetch	Cotton (vetch)		950	1,137
2-year rotations:				
No. 20	Cotton (sweetclover), grain sorghum (vetch)		1,178	1,254
No. 22	Cotton (cowpeas), grain sorghum		862	881
No. 23	Cotton, grain sorghum (manure)		1,298	1,206
3-year rotations:				
No. 30	Cotton (sweetclover), grain sorghum, barley (sweetclover) corn.		703	740
4-year rotations:				
No. 40	Cotton (2 years), alfalfa (1½ years) corn	first year	1,756	1,595
		second year	1,126	1,388
No. 44	Cotton (2 years), alfalfa (2 years)	first year	1,743	1,741
		second year	1,464	1,315
No. 46	Cotton, alfalfa (2 years), barley, grain sorghum		1,371	1,448
5-year rotations:				
No. 50	Cotton, alfalfa (3 years), barley, grain sorghum		994	1,240
No. 52	Cotton, alfalfa (3½ years), grain sorghum		1,505	1,421
6-year rotations:				
No. 60	Cotton (2 years), alfalfa (3 years), barley, grain sorghum.	first year	1,102	1,351
		second year	881	1,222
No. 61	Cotton (2 years), grain sorghum, alfalfa (harvested with hogs third year).	first year	1,295	1,841
		second year	987	1,609
No. 63	Cotton (2 years), barley, alfalfa (2½ years, harvested by hogs, March to July, third year).	first year	1,791	1,776
		second year	1,304	1,626
Mean			1,249	1,377

Information on the practice of growing cotton continuously on the same land, untreated, as compared with growing it on plots to which treatments have been applied, as well as in rotation with other crops, is of special importance, since many farmers on the Yuma project wish to utilize as much land as possible in the production of cotton. From four different plots continuously in cotton, the results of 8 years have been obtained. The largest yield from any of the rotations is

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from plot 5 continuously in cotton and receiving an application of manure in alternate years. Furthermore, there is no evidence of a decline in yield as the practice is continued, for the last 4-year period has returned a yield of 118 pounds per acre in excess of that recorded for the period 1923–26. These results indicate that if there are frequent applications of manure, cotton yields may be maintained over a period of several years when the crop is grown continuously on the same land.

Relatively low yields are recorded from plot 4 continuously cropped, which has had a biennial application of 400 pounds of commercial fertilizer; and when the yields from the two 4-year periods are compared it is evident that they are scarcely being maintained. In comparing the yields for the 1927–30 period of this plot with those from no. 6, untreated, it is observed that there is a difference of only 90 pounds of cotton per acre in favor of the fertilized plot, which does not justify the cost of the fertilizer.

Somewhat comparable results are shown for plot 7, which has a winter crop of vetch sown in the fall and plowed under in the spring, although when the results from the two 4-year periods are compared there is some evidence of a slightly beneficial effect due to the vetch. However, when the yields for the last 4-year period from this plot are compared with those from no. 6, there is a difference of only 81 pounds of seed cotton per acre, an increase which does not compensate for the expense of the treatment.

In rotations 20 and 22, vetch, sweetclover, and cowpeas are included for the purpose of determining to what extent such crops may be expected to improve cotton yields when plowed under. In most cases the growth of the green-manure crop has been so limited that it is not to be expected that such treatment would materially influence cotton yields. This is confirmed by the actual yields. The average yields of these two plots for the 1927–30 period of 1,068 pounds of seed cotton per acre is only 12 pounds more than from plot 6 continuously in cotton and receiving no treatment. Furthermore, when the yields for the first 4-year period are compared with those for the second 4-year period it will be observed that there has been but a slight increase and no more than the increase obtained during the second period from the continuously cropped plot 6.

No better results were shown in rotation 23, which is a 2-year rotation with grain sorghum but which has one application of manure during the cycle, immediately preceding cotton. It is apparent that grain sorghum has lessened the yields of cotton, and even when manure is applied the yields have scarcely been maintained. The influence of grain sorghum on the yields of cotton may be measured by comparing the yields of cotton in this rotation with those from continuously cropped plot 5. In both cases there is a biennial application of manure, the difference being the substitution of grain sorghum for 1 year of cotton. For the last 4-year period the yield of cotton from plot 5 exceeds that from rotation 23 by 709 pounds of seed cotton per acre.

The lowest yields, 703 and 740 pounds of seed cotton, recorded for any of the rotations for both periods are from rotation 30, which has two crops of grain sorghum and one crop each of barley and corn. This is an intensive cropping system of such a nature that it might not be expected to result in satisfactory cotton yields. Such benefits as

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might be expected to be derived from two green-manure crops of sweetclover are not reflected in the cotton yields, as the sweetclover in the first instance where it appears in this rotation is three crops removed from cotton and the second time a corn crop precedes cotton. On this plot in 1931 the roots of the cotton plants showed evidences of severe nematode injury, which it was believed adversely affected the yields. However, it has been apparent, even after allowing for nematode injury, that the depressing effects of grain sorghum on the yields of cotton are again emphasized in this cropping sequence as in rotation 23.

In this series of three 4-year alfalfa rotations, nos. 40, 44, and 46 were included. These rotations have a cropping program that makes it possible to observe the effects on the yields of cotton when this crop immediately follows alfalfa and also when there is an intervening crop. It was desired to ascertain whether, in case the stimulation resulting from alfalfa should cause too vigorous growth of the cotton plants, larger yields would result if the productivity of the soil was somewhat reduced by intermediate cropping. Under conditions existing where these investigations are being conducted, the yields indicate that better results may be expected when cotton immediately follows alfalfa. For the last 4-year period, rotation 44–1 returned a yield of 146 pounds of cotton in excess of no. 40–1, which has a corn crop between the alfalfa and cotton, and 293 pounds in excess of 46, with barley and grain sorghum intervening. Both nos. 40 and 44 have two years of cotton during their cycle; and while the yield of the second crop is materially less than that of the first, the average for the two periods is in favor of no. 44.

The favorable influence of two years of alfalfa on the yield of cotton is apparent when the first-year yields from rotation 44 are compared with those from continuously cropped plot no. 6. For the 1927–30 period there is a difference of 685 pounds of seed cotton per acre in favor of the alfalfa rotation. This difference is reduced to 259 pounds when the second crop of cotton in rotation 44 is considered separately.

On the other hand, 2 years of alfalfa have not stimulated yields even the first year as much as when manure is applied in alternate years. This is evident when the yields from continuously cropped and manured plot no. 5 are compared with the three 4-year alfalfa rotations.

Of the two 5-year rotations one (no. 50) has alfalfa for a period of 3 years, and in the other (no. 52) the alfalfa land is not plowed in the fourth year until June. In both rotations grain sorghum precedes cotton, but in no. 50 a crop of barley precedes the grain sorghum. Shortening the period that alfalfa was grown and the substitution of barley have lessened yields in both the 1923–26 and 1927–30 periods, there being a difference of 511 and 181 pounds of cotton, respectively, in favor of the 3½ years of alfalfa.

Rotations 46 and 50 are identical as to crops, treatments, and sequences except that no. 50 has one more year of alfalfa. A comparison of the yields from these two cropping systems would indicate, at first glance, that this extra year of alfalfa has depressed yields. However, it is evident that the original productivity of the soil has influenced the results, as will be observed from the annual yields in table 2. There has been a definite tendency for rotation 50 to give materially lower yields than rotation 46, particularly during the earlier

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years. Therefore, the merits of the two cropping systems may be judged better by considering the yield trends. In the case of no. 46 the difference between the two periods is 77 pounds of cotton in favor of the second period. On the other hand, in rotation 50 there is a difference of 246 pounds in favor of the second period, indicating possibilities of still further improvement.

Of the three alfalfa rotations requiring 6 years to complete their cycle, the alfalfa is harvested by hogs in two, nos. 61 and 63. In no. 61 the alfalfa is pastured from March to October, and in no. 63 the pasturing period is from March until June. Rotation 60 is identical with no. 50 except that the former has 2 years of cotton instead of 1. The slight differences in yields between these two cropping systems are in favor of rotation 60. This is to be expected, for both include 3 years of alfalfa. Cotton is grown 2 successive years in each of these rotations. From alfalfa rotations the largest average yield (1,841 pounds per acre) was harvested from first-year crops of rotation 61 during the second 4-year period. The only cropping system which has exceeded this yield during the second 4-year period is plot 5, continuously cropped and manured. The indicated advantages of this cropping program are even more apparent when the two 4-year periods are compared for each of the 2 years cotton is grown. The yield in the second 4-year period exceeds that in the first by 622 pounds the first year and by an equal amount the second year. This is a greater increase than is shown under any of the other cropping systems.

The yields from rotation 63 for the 4-year period 1927–30 are approximately equal to those from rotation 61 (fig. 2). However,

FIGURE 2.—Pima cotton in rotation 63–1 following 2½ years of alfalfa, last spring growth harvested with hogs followed by corn. Photographed shortly before the first picking in 1930. Yield 2,220 pounds of seed cotton per acre, equivalent to 578 pounds of lint cotton.

when both 4-year periods are compared, the superiority of the former is apparent. These results indicate that corn substituted for a full season's pasturing of alfalfa may be expected to decrease cotton yields somewhat.

The residual effect on cotton yields of pasturing alfalfa is reflected in both rotations in the second-year yields for the last 4-year period.

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The two rotations in question, nos. 61 and 63, have given yields of 1,609 and 1,626 pounds, respectively, which exceed those obtained from any other of the rotations having 2 successive years of cotton.

RESULTS FROM THE 1928 ROTATIONS

In 1928, nine additional rotations were added to the 1923 series, the results from which have been discussed in the foregoing pages. These were included for the purpose of obtaining information regarding crop sequences and treatment not covered by the first series and about which questions were raised subsequent to 1923. As the results of only 3 years are as yet available, it is not to be expected that the differences in the yields obtained would reflect the yield trends due to the crop sequences or treatments. However, the data given in table 5 do furnish further information on the yields to be expected from Pima cotton under somewhat more favorable conditions than those existing at the time the 1923 series was started.

TABLE 5.—*Acre yields of Pima seed cotton (pounds) from the irrigated rotations of the 1928 series at the Yuma Field Station,*[1] *1928–30*

Rotation no.	1928	1929	1930	Mean, 1928–30	Rotation no.	1928	1929	1930	Mean, 1928–30
7–a	1,580	1,726	1,968	1,758	56	2,028	1,816	2,544	2,129
7–b	1,808	1,468	2,068	1,781	64–1	2,040	1,860	2,164	2,021
31	1,324	1,500	1,860	1,561	64–2	1,784	1,604	2,040	1,809
34–1	1,992	2,410	1,932	2,111	64–3	1,904	1,412	1,700	1,672
34–2	1,996	1,514	2,104	1,871	65–1	2,076	1,346	1,988	1,803
36–1	2,024	2,156	2,224	2,135	65–2	1,944	1,474	1,884	1,767
36–2	2,160	1,546	2,004	1,903					
54–1	1,996	1,990	2,244	2,077	Average	1,909	1,707	2,040	1,885
54–2	1,972	1,782	1,872	1,875					

[1] A detailed description of these rotations together with their locations appears on pp. 10 and 11.

The land now occupied by these rotations had been rather intensively cropped, chiefly to soil-improvement crops such as alfalfa, for several years prior to 1928, and consequently was in a relatively high state of productivity when included in the series. This is evidenced by the mean yields for all of these rotations for the 3-year period, which is 1,885 pounds of seed cotton per acre, as compared with a mean of 1,436 per acre during the 1928–30 period for the series started in 1923. The largest yield recorded in table 5 from all rotations for the 3-year period is from no. 56 in 1930, 2,544 pounds of seed cotton per acre. The lowest yield is from rotation 31 in 1928, when only 1,324 pounds per acre was obtained.

Rotation 64 is so arranged that in addition to its other features it has three successive crops of cotton. The 1930 results in this rotation are of interest, as it is the only one in either series in which three consecutive years of cotton follow alfalfa. The yields of the three crops for the three years beginning with 1928 are 2,021, 1,809, and 1,672 pounds of seed cotton per acre, respectively. This indicates a decline in yield between the first- and third-year crops amounting to 349 pounds from land which was previously relatively productive.

The yields obtained from rotation 31 indicate the extent yields may be maintained under severe cropping conditions by applications of manure. From this rotation one crop of cotton and two crops each of barley and grain sorghum are harvested during the 3-year cycle.

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The mean yield for the 3-year period has been 1,561 pounds of seed cotton per acre, and in 1930 the yield was 1,860 pounds (fig. 3).

The highest mean yield for the 3-year period, 2,135 pounds of seed cotton per acre, was harvested from no. 36–1. The second-year yield from this same rotation was also high, the mean being 1,903 pounds

FIGURE 3.—Pima cotton following grain sorghum, manured, rotation 31, Yuma Field Station. Yield, 1,860 pounds of seed cotton per acre. December 1930.

per acre. The mean of these two is 2,019 pounds of seed cotton, which is equivalent to 525 pounds of lint per acre.

RESULTS FROM DIFFERENT SPACINGS

There is a wide divergence of opinion among cotton growers as to the space that should be left between cotton plants at the time of chopping or thinning in order to obtain the highest yields. In order that information on this subject might be obtained, beginning with the season of 1925 cotton plants on one half of each of the plots in these rotations were spaced as nearly as practicable 7 inches and the other half 14 inches apart. To eliminate outside-row effect in computing the yields, the first and last rows of each plot were not included. Often the specified spacings of the plants do not show a close relationship to the actual average distance apart at the end of the season. The plants are usually thinned when 6 to 8 inches high or when well established; and if weather and other conditions have been favorable and accidental injuries have not occurred, the resulting stand does not deviate greatly from the desired 7- and 14-inch distances. However, conditions have not always been favorable, and the result has been average spacings greater than was intended.

In order that differences in yield attributable to difference in spacing might be recorded, counts of the total number of plants were made at the end of the season, and their average distance apart was determined by dividing the total length of the rows by the number of plants. The results of the variation in the spacings and yields

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from the different rotations throughout the six years are given in detail in table 6. The two spacing distances are designated as "wide" and "close." The difference in yield from the two spacings is expressed as the difference between the two blocks in each plot in pounds of seed cotton per acre. A minus sign preceding the figure in the column headed "Yield difference" indicates the deficiency in pounds of seed cotton per acre which may be attributed to extended spacings. All other yield figures represent increases which may be attributed to close spacings. The mean distances for each of the two spacings and the mean yield differences for each year are given for all rotations. To afford an opportunity of observing such relationship as has existed between spacing distances and yields, the mean yields for all the cropping systems for the 6-year period are recorded in the last column of the table.

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TABLE 6.—*Average distance apart of the cotton plants in the rows of the different rotations together with the indicated deficiencies and increases in yields as influenced by extended as compared with close spacings, at the Yuma Field Station, 1925–30*

Rotation no.	1925			1926			1927			1928			1929			1930			Mean difference	Average yield per acre
	Spacing average		Yield [1] difference	Spacing average		Yield [1] difference	Spacing average		Yield [1] difference	Spacing average		Yield [1] difference	Spacing average		Yield [1] difference	Spacing average		Yield [1] difference		
	Extended	Close		Extended	Close		Extended	Close		Extended	Close		Extended	Close		Extended	Close			
	Inches	*Inches*	*Lbs.*	*Inches*	*Inches*	*Lbs.*	*Inches*	*Inches*	*Lbs.*	*Inches*	*Inches*	*Lbs.*	*Inches*	*Inches*	*Lbs.*	*Inches*	*Inches*	*Lbs.*	*Lbs.*	*Lbs.*
4	14.1	10.3	−432	14.4	9.8	−240	12.8	10.9	−55	17.7	9.6	−110	15.5	9.3	175	14.5	9.3	−155	−136	1,255
5	14.9	11.0	230	15.1	9.7	225	13.1	10.2	130	12.9	9.0	225	14.8	13.0	−140	15.5	10.1	42	119	2,106
6	14.3	10.3	−100	14.6	9.4	−135	12.4	10.2	−55	14.1	9.8	−110	15.6	9.8	−170	15.0	10.2	−148	−120	1,115
7	15.2	11.2	−105	15.5	10.8	25	20.3	21.9	90	12.4	10.6	−50	21.8	4.1	−140	17.3	12.1	105	−13	1,167
7-a										15.2	10.0	−360	13.0	10.1	120	17.6	11.5	−327	−189	1,758
7-b										15.5	10.3	80	13.0	9.4	−45	17.2	13.8	105	47	1,781
20	14.8	10.7	−280	17.2	14.3	375	23.8	20.8	−270	22.5	15.7	50	13.2	10.2	190	15.7	12.5	335	67	1,376
22	13.2	9.9	−70	14.9	11.7	65	18.7	10.2	100	13.9	9.2	−80	19.1	12.9	75	30.3	26.3	−60	5	957
23	14.3	11.2	−55	15.1	11.5	40	14.4	10.6	−95	14.4	9.5	−20	19.1	13.7	85	28.9	23.2	−75	−20	1,356
30	14.1	11.8	245	17.2	11.5	−5	17.8	19.6	−105	14.6	9.1	−50	19.5	14.4	40	17.8	15.6	5	22	839
31										13.3	10.7	1,015	13.4	10.5	40	14.4	10.5	277	444	1,561
34-1										14.2	8.5	405	16.2	10.1	−160	13.9	9.1	140	128	2,111
34-2										13.2	9.1	425	18.0	13.2	175	14.7	9.1	20	207	1,871
36-1										13.8	8.3	400	19.3	15.2	−85	17.8	11.6	428	248	2,135
36-2										13.4	10.7	750	19.8	13.6	−360	15.7	11.4	32	141	1,903
40-1	14.1	10.8	340	15.5	10.6	−805	17.1	11.6	−205	16.2	8.4	−340	18.2	12.6	30	15.6	10.7	−150	−188	1,955
40-2	12.4	10.6	15	15.1	10.4	142	14.3	11.1	−420	17.9	10.5	−240	18.9	14.8	185	15.5	12.3	−793	−185	1,460
44-1	14.2	11.4	−350	15.8	11.4	42	14.5	10.5	90	16.8	12.3	−55	16.7	10.3	145	15.4	10.6	247	20	1,799
44-2	13.5	10.5	−215	15.8	10.2	−160	15.9	9.6	215	18.2	9.4	25	18.7	22.1	335	15.1	10.8	170	62	1,525
46	13.3	9.4	−155	15.1	9.8	60	14.3	8.8	220	15.1	9.6	−365	18.3	12.8	85	19.3	15.0	−270	−71	1,481
50	13.7	10.3	−130	16.0	10.6	−215	13.8	10.3		13.7	8.2	125	13.6	11.2	190	13.8	9.0	95	11	1,256
52	13.6	9.4	−670	15.0	10.0	−455	14.9	11.9	5	14.2	9.6	−90	13.8	10.0	−370	14.6	10.9	−242	−304	1,702
54-1										13.8	8.9	−95	17.0	12.9	−125	15.6	8.8	−20	−80	2,077
54-2										12.9	8.9	90	14.4	9.2	−285	14.2	9.2	−25	−73	1,875
56										12.7	8.5	−170	16.0	10.3	−250	15.1	8.4	−113	−178	2,129
60-1	13.1	9.9	−320	14.9	10.4	−17	12.1	8.9	−205	14.4	9.3	−105	15.2	10.7	110	13.3	8.2	−118	−109	1,370
60-2	12.2	8.7	−80	14.6	10.2	−440	11.9	8.6	−120	13.2	8.9	−205	14.9	8.7	5	14.9	10.0	−183	−171	1,232
61-1	12.9	9.8	−100	17.5	13.1	−80	12.9	10.1	360	16.6	12.7	−675	16.2	10.4	−635	14.1	8.1	−62	−199	1,840
61-2	12.8	10.3	−35	15.2	9.7	−35	13.9	10.9	−125	14.3	9.1	170	14.8	10.4	265	14.4	10.3	130	62	1,480
63-1	13.7	10.4	−555	15.6	10.3	285	13.1	8.8	20	17.6	11.6	−280	14.2	10.2	125	14.2	9.9	−95	−83	1,876
63-2	13.6	9.4	10	14.4	10.3	−60	12.5	9.7	75	14.3	9.4	−35	15.2	8.9	30	13.3	8.9	100	20	1,652
64-1										13.0	8.5	80	18.4	17.5	110	16.3	8.8	88	93	2,021
64-2										13.3	7.8	135	18.2	15.3	−15	12.7	7.5	30	50	1,809
64-3										13.1	7.5	95	17.5	14.2	−170	15.2	9.2	−298	−124	1,672
65-1										14.8	8.9	195	18.6	12.5	45	14.5	9.0	155	132	1,803
65-2										13.0	8.4	160	18.4	14.1	−30	13.7	9.5	−135	−2	1,767
Mean	13.7	10.3	−124	15.5	10.7	−66	15.0	11.7	−17	14.7	9.6	28	16.6	11.9	−12	16.0	11.2	−21	−10	1,641

[1] Figures preceded by minus sign (−) indicate deficiency in pounds of seed cotton per acre which may be attributed to extended spacing. All other yield figures imply increases which may be attributed to close spacing.

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The increased yields often obtained as a result of having the cotton plants somewhat closer together than in ordinary practice have been emphasized in several publications (*2, 5, 10, 11*). Investigations have shown that while under certain conditions plants spaced 18 inches to 2 feet or more apart may yield as well or better than plants more closely spaced, yet over a long period it has been found that higher yields result from relatively close spacing. Leaving the plants close together in the row restricts their size and retards the development of the objectionable vegetative branches.

Aside from the increased yield per acre usually obtained from smaller plants, there are other advantages of close spacing of Pima cotton under irrigated conditions. The vegetative branches being suppressed, the plants in the row are smaller and more compact, affording better exposure of the fruiting branches to the sun and permitting cultivation later in the season. Large plants with long vegetative and fruiting branches are more subject to injury by windstorms, and difficulty is encountered by the laborers at picking time, caused by the breaking off of the large branches produced by widely spaced plants. This often results in material loss before subsequent pickings are made. Owing to close supervision of the pickers under the conditions existing where these investigations were conducted, the losses were undoubtedly materially less than would be likely to occur under average farm conditions. Consequently, it seems probable that the yield figures recorded in table 6 reflect more favorable results for the wider spacings than would be the case under ordinary conditions where special precautions cannot be taken to avoid plant injury during the early pickings.

The yield differences with the two spacing distances recorded in table 6 indicate that a wide variation may be expected when comparisons are made of several years' results, even from fields which have received uniform treatment. Equally wide fluctuations are to be expected during the same year when Pima cotton has been subjected to a wide range of cultural treatments. Other factors, such as soil variation which markedly influences the type of plant produced, are at times favorable for heavy fruiting and at other times unfavorable. However, with a mass of data covering a 6-year period, certain yield trends may serve as a basis for the grower to decide the spacing distance likely to return the largest yields.

In considering the means of all rotations for the 6-year period, the yields recorded are in favor of the close spacings each year with the exception of 1928, when the mean difference in yield was 28 pounds of seed cotton per acre in favor of the extended spacings. The greatest difference in the yearly means occurred in 1925, when 124 pounds per acre in favor of the close spacings were harvested. These results indicate further that seasons when high average yields are obtained are not necessarily years when extended spacings may be expected to influence production more favorably, as is apparent when the yearly mean yields given in table 2 are compared with the differences in table 6. The highest mean yield of all rotations for the 8-year period was in 1926, the year when the second largest difference in favor of close spacing was recorded.

It is possible so to combine the detailed results that the effect on yields from average spacings of 16 inches or more may be compared with those where the plants averaged 10 inches or less apart. Elimi-

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nating the year 1925, when no spacings equaled or exceeded 16 inches, there were 54 plots during the years 1926–30 on which the plants averaged 16 inches or more apart. From these 54 plots the average yield was 1,510 pounds of seed cotton per acre. For the same period 64 plots, with an average spacing distance of 10 inches or less, yielded an average of 1,797 pounds of seed cotton, or a difference in favor of the closer spacing of 287 pounds of seed cotton per acre.

While relatively close spacing of cotton plants usually is recognized as a desirable practice, it is often contended that on land which is highly productive better results may be obtained if the distance between the plants is increased somewhat. An opportunity of obtaining information on this question is afforded by segregating the mean differences in all yields below 1,500 pounds of seed cotton per acre from those returning a yield above that figure. There are 13 rotations having a mean yield of less than 1,500 pounds and 23 with mean yields in excess of 1,500 pounds of seed cotton. The lower-yielding group showed a yield of 51 pounds of seed cotton per acre in favor of close spacing, whereas the higher-yielding group produced 13 pounds of seed cotton per acre in favor of the extended spacings. These results indicate that on land which is highly productive slightly better per acre yields may be expected if the grower adopts the wider spacing. However, it should be remembered that the losses sustained in the lower-yielding group of 13 rotations, producing less than 1,500 pounds of seed cotton per acre, more than offset the slight increase recorded for those returning a yield in excess of that figure.

POSSIBILITIES OF PIMA EGYPTIAN AND UPLAND COTTONS COMPARED

Successful farming on irrigated land often depends upon taking advantage of local conditions that permit of the growing of specialized crops or varieties of superior quality commanding a market premium above those more generally produced. In this class of specialty crops is Pima Egyptian cotton which is adapted only to the arid conditions found in the interior valleys of southern Arizona and California. The advantages of this variety over upland cotton, which is so extensively grown that large surpluses and very low prices frequently result, has been recognized for many years by the Department of Agriculture (*1, 4, 8, 9, 12, 13*).

Commercial acreages of Pima cotton have been produced since 1916, chiefly in the Salt River Valley of Arizona. For the 3 years prior to 1920 the production of this cotton was distinctly more profitable than that of any of the upland types then being grown. This resulted in material expansion of acreage, and much land was planted to the crop which would not produce profitable yields. This was the case not only in the Phoenix area, but extensive plantings in 1920 were also made in other irrigated sections, notably in the Yuma and Imperial Valleys.

The economic adjustments during the latter part of 1920 and the 2 years following caused much confusion among growers as to what variety of cotton would be likely to prove profitable. The price differential between Pima and upland was greatly narrowed in 1922 and 1923, having varied between about 14 percent and 28 percent in favor of Pima, as compared with slightly more than 100 percent for the years 1924–31. These unusual price relations, together with

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the greater cost of picking and ginning Pima and the rather general belief that it is much less productive than upland cotton, caused many farmers to abandon Pima and substitute upland varieties. In many instances this dissatisfaction with Pima may have been due to the fact that yields were lower than those previously obtained. Many growers, therefore, concluded that more satisfactory results would be obtained by the substitution of upland for Pima. The benefits expected have not been realized, and experienced growers have found that upland cotton is fully as susceptible as Pima to unfavorable growth conditions, and often more so.

In determining which variety of cotton is likely to be the most profitable over a series of years, a number of factors must be taken into consideration. Among these are: (1) Yield differences, (2) comparative production costs, (3) probable differences in the market value of the lint, and (4) the advantages of an increased and continuing supply which will more adequately meet present as well as prospective trade requirements.

No data are available as to the comparative yields of the two types of cotton under the same conditions in the Yuma Valley. However, the results recorded in tables 2, 4, 5, and 6 provide information as to the yields which may be expected from Pima under a relatively wide range of cropping conditions during a period of several years. The average yield of Pima seed cotton for all rotations for the period 1925–30, as given in table 6, is 1,641 pounds, which is equivalent to 427 pounds per acre of lint. For the same period the Bureau of Reclamation, Department of the Interior, reports a yield of upland cotton on the Yuma project of 414 pounds of lint per acre, or 13 pounds less than the mean yield for all the rotations. From the foregoing it should not be assumed that the Pima variety may prove to be more productive than upland types of cotton in the Yuma Valley, for it is not likely that such will be the case. In the Salt River Valley the recorded yields of commercial acreages of both types of cotton for the period 1923–31, as reported by the Bureau of the Census, Department of Commerce, have shown a difference in yield of 64 pounds of lint per acre in favor of upland cotton.

Information relative to comparative production costs between Pima and upland has been made available as a result of investigations conducted in the Salt River Valley of Arizona, where commercial acreages of Pima have been grown each year since 1916.[6] It has been found that as far as the per acre costs are concerned Pima can be produced as cheaply as upland with the exception of picking and ginning. For the 7-year period 1922–28 the difference in cost of picking and ginning has amounted to approximately 6 cents per pound of lint during a period when lint values and production costs were materially in excess of those now prevailing. It appears that present values have had a tendency to reduce the difference.

The production of commercial quantities of Pima cotton in the Salt River Valley during 16 years affords a basis for observing price fluctuations. During most of these years data are available for comparing the prices obtained for Pima and upland cottons at Phoenix. The prices paid on December 1 for both types of cotton at Phoenix, Ariz., since 1913 are available except for the years 1918–21, when no

[6] STEWART, H. A. REPORT OF THE COTTON COMMITTEE. Mimeographed unnumbered Circ., 17 p. 1929

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upland cotton was grown in that part of the State.[7] Prices and the differential in prices for the two types during the period of the World War and for a few years following may be assumed to have been abnormal. Consequently, in table 7, only 8 years are considered, 1924–31. In this table are recorded prices paid for Pima and upland cottons at Phoenix, Ariz., on December 1, for each year of the 8-year period, together with the differences.

TABLE 7.—*Comparative December 1 price quotations, in cents per pound of lint, for Pima Egyptian no. 2 and middling upland cotton at Phoenix, Ariz., 1924–31*

Cotton and grade	1924	1925	1926	1927	1928	1929	1930	1931	Mean
Pima Egyptian no. 2	47	41	31	38	38.3	31.0	17.5	15.5	32.4
Middling upland	23	22	14	20	20.0	17.1	8.7	5.8	16.3
Difference	24	19	17	18	18.3	13.9	8.8	9.7	16.1

There are opportunities for a greatly increased production of the Egyptian long-staple cotton in the Southwest. If production and marketing could be stabilized and the quality maintained at a sufficiently high standard it is believed that there would be a market for an amount materially in excess of that now produced (*4*). For the years 1923–30 the Census Bureau figures report a production of American Egyptian ranging from a minimum of 4,319 bales in 1924 to a maximum of 28,771 bales in 1929, an average of only 20,949 bales for the 8-year period, or less than one twentieth of the consumption possibilities in this country alone. For the past several years the interest of buyers and consumers in this cotton has fluctuated, but this is natural when it is considered that not only has the average production been limited but that it has varied greatly from year to year. Unlike the position of most agricultural commodities, of which there are often large surpluses, it is believed that a substantially increased and stabilized production of Pima lint of a high quality would react favorably on its market value.

The tabulated yields, particularly from the better rotations, recorded in tables 2 and 4, together with the results obtained from the better lands in the Salt River Valley, indicate that the Pima variety of cotton has distinct possibilities as a substitute for the inferior types now generally grown. However, it is highly essential that growers be cautioned regarding the importance of growing and preparing for the market fiber high in quality and uniform in character. The indicated premium paid for Pima lint as compared with Middling upland for the past several years is substantial, but growers cannot be expected to take advantage of such a situation unless soil conditions are favorable, plant growth satisfactorily maintained throughout the fruiting season, the crop properly harvested, and the ginning well performed. These requirements are fundamentally essential in preparing for the market a high-class product; and unless these conditions are adequately met, the grower is likely to be disappointed in his venture.

While relatively large yields are essential if Pima cotton is to be profitable, yet placing a uniform product of high quality is also neces-

[7] These prices were obtained and recorded at the county agent's office at Phoenix, Ariz., and were supplied by Harry A. Stewart, Maricopa County agricultural agent.

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sary (*3*). Mixed varieties and diversity of plants in the field are not the only causes of inequality of lint. Prospective growers should understand that in order to harvest a product of the necessary high quality not only must soil conditions be favorable but that growth conditions conducive to normal healthy plant development must be maintained throughout the growing season. Because of the rather extreme temperature conditions that often prevail during the summer months in the Yuma Valley, an adequate supply of soil moisture should be maintained at all times in order to avoid severely checking the growth of the plants. Soil variations are common, and if known to be pronounced and impossible of correction in certain fields, such fields should be avoided. If growth conditions are definitely unfavorable, only inferior staple, often lacking in uniformity, will be harvested. It is evident, then, that a highly important element in the success to be attained by those who are engaged in the production of Pima Egyptian is predicated upon the knowledge acquired and the success attained in the avoidance of the mixtures of different qualities of lint in the bale.

SUMMARY

Agronomic investigations relating to problems of crop production in the Yuma Valley have been conducted since 1906 at the Yuma Field Station. As cotton has been one of the more important crops in acreage, a large part of the work of the station has been the obtaining of information regarding types and varieties of cotton, planting methods, irrigation, and tillage practices.

Out of the large number of varieties tested, Pima Egyptian was selected as the one that it was believed would prove, in the long run, to be the most profitable to grow. This variety has been grown in the rotation experiments herein reported.

Soil conditions in the Yuma Valley are typical of the eastern side of the Colorado River Delta. The surface soil is often quite variable, ranging from coarse sand to fine silt, with a subsoil through which water penetrates readily.

The climate is characterized by a long growing season free from frost, with relatively high summer temperatures and mild winters. Only rarely are there minimum temperatures as low as 16° F. By judicious selection of crops, advantage may be taken of a 12 months' growing season.

Cultural practices are discussed, together with the planting and harvesting dates of the crops grown in the rotations that include cotton.

The chief object of these rotations was to obtain information as to the most logical rotation or rotations and as to the effects upon the maintenance and improvement of cotton yields, of commercial fertilizers and stable manure, and of soil-improvement crops, such as vetch, cowpeas, clover, and alfalfa. Information has been obtained on this subject by comparing continuously cropped cotton plots variously treated with those in a rotation with other crops for two or more years. Consideration is given to the effect on the yield of cotton of an immediately preceding crop such as sorghum, corn, and barley. Comparison is made of the effect of alfalfa on the yields of cotton when the alfalfa has been left in two and three years, respectively. Such rotations are compared with others where cowpeas, clover, and vetch are used as the leguminous crop.

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The original series of 16 rotations was started in 1923, to which 9 were added in 1928, making a total of 25.

The yields in detail for the 6-year period are given, which afford an opportunity to compare the results in ways other than those discussed.

These tabulated data indicate a relatively wide annual fluctuation in the yields from all rotations. To compensate for this factor, the annual yields from each rotation are expressed as a percentage of the annual means of all rotations in table 3. These percentage figures permit of a more direct comparison, as they compensate for seasonal variations throughout the 8-year period.

The summarized effects of the different rotations and treatments applied are tabulated and discussed. The mean yield of the first 4-year period is compared with the mean yield for the second 4-year period of each rotation for the purpose of observing the trends in yield.

The largest yields for both 4-year periods are those from plot 5, continuously cropped and manured, and the lowest from 3-year rotation 30, which has four major crops during its cycle. Commercial fertilizers appear to have influenced the yields only slightly. Green-manure crops, such as vetch, clover, and cowpeas, have not been particularly beneficial. Alfalfa has increased the yields of cotton in every instance as compared with simple rotations not including this crop. Better results were obtained when the last year of alfalfa was pastured than when it was cut for hay.

The results of the rotations added in 1928 are given. The yields from this series are materially higher than those of the original series (table 2), largely because of the general improvement of the soil at the station since the first series was started. In rotation 64 of this series it is possible to observe the effect of 3 successive years of cotton following alfalfa.

Since 1925 one half of each plot in these series of rotations has been thinned so that the plants were spaced, as nearly as possible, 7 inches apart, and the other half of each plot has been thinned to give an approximate spacing of 14 inches. Comparisons of the results from the two spacing distances are given in detail.

Results, although not entirely consistent, are, as a rule, in favor of the closer spacings. A comparison of the averages in all rotations for the last 6 years for plants spaced 16 inches or more and plants spaced 10 inches or less showed an average of 287 pounds of seed cotton per acre in favor of the closer spacing.

In the case of the higher-yielding rotations there was a slight tendency for the wider spacings to outyield the closer spacings, while the reverse was true of the less-productive rotations.

The comparative merits of Pima Egyptian and upland cottons are discussed on the basis of yields of Pima obtained in these rotations, the price differential which has existed, and the difference in production costs between the two varieties in the Salt River Valley.

It may be concluded that on productive land in the lower Colorado River region Pima cotton is likely to prove more profitable than upland.

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LITERATURE CITED

(1) Cook, O. F.
1913. FACTORS AFFECTING THE PRODUCTION OF LONG-STAPLE COTTON. U.S.Dept.Agr., Bur. Plant Indus. Circ. 123 : 3–9.

(2) ———
1914. SINGLE STALK COTTON CULTURE. U.S.Dept.Agr., Bur. Plant Indus. B.P.I. 1130, 11 p., illus.

(3) ———
1914. THE RELATION OF COTTON BUYING TO COTTON GROWING. U.S. Dept. Agr. Bul. 60, 21 p.

(4) ———
1930. COTTON OF LONG STAPLE COULD BE PRODUCED IN MUCH GREATER QUANTITY. U.S. Dept. Agr. Yearbook 1930 : 202–207, illus.

(5) ——— and Martin, R. D.
1924. CULTURE OF PIMA AND UPLAND COTTON IN ARIZONA. U.S. Dept. Agr. Farmers' Bul. 1432, 14 p., illus.

(6) Hastings, S. H.
1917. A LISTER ATTACHMENT FOR A COTTON PLANTER. U.S.Dept.Agr., Bur. Plant Indus., C. P. & B. I. 2, 3 p., illus.

(7) ———
1932. IRRIGATION AND RELATED CULTURAL PRACTICES WITH COTTON IN THE SALT RIVER VALLEY OF ARIZONA. U.S. Dept. Agr. Circ. 200, 31 p., illus.

(8) Hunter, B., and Stewart, H. A.
1929. RETURNS FROM DIFFERENT SYSTEMS OF FARMING ON THE SALT RIVER VALLEY IRRIGATION PROJECT. Ariz. Agr. Col. Ext. Circ. 60, 62 p.

(9) Kearney, T. H.
1927. COTTON OF AMERICAN-EGYPTIAN VARIETY IN U.S. U.S. Dept. Agr. Yearbook 1926:251–254., illus.

(10) King, C. J., and Leding, A. R.
1926. AGRICULTURAL INVESTIGATIONS AT THE UNITED STATES FIELD STATION, SACATON, ARIZ., 1922, 1923, AND 1924. U.S. Dept. Agr. Circ. 372, 46 p., illus.

(11) ——— and Loomis, H. F.
1932. AGRICULTURAL INVESTIGATIONS AT THE UNITED STATES FIELD STATION, SACATON, ARIZ., 1925–1930. U.S. Dept. Agr. Circ. 206, 64 p., illus.

(12) ——— Loomis, H. F., and Varmette, D. L.
1924. COMPARISON OF PIMA COTTON WITH UPLAND VARIETIES IN ARIZONA. Jour. Agr. Research 28:937–954, illus.

(13) Scofield, C. S., Kearney, T. H., Brand, C. J., Cook, O. F., and Swingle, W. T.
1919. PRODUCTION OF AMERICAN EGYPTIAN COTTON. U.S. Dept. Agr. Bul. 742, 30 p.

(14) Westover, H. L., and Noble, E. G.
1926. FERTILIZER EXPERIMENTS WITH ALFALFA CONDUCTED AT THE UNITED STATES YUMA FIELD STATION, BARD, CALIF., 1919 TO 1925. U.S. Dept. Agr. Bul. 1418, 11 p., illus.

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BRUISING AND FREEZING OF APPLES IN STORAGE AND TRANSIT

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TECHNICAL BULLETIN No. 370 September 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

BRUISING AND FREEZING OF APPLES IN STORAGE AND TRANSIT

By DEAN H. ROSE, *senior physiologist*, and J. M. LUTZ, *junior physiologist*, *Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*[1]

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INTRODUCTION

Rather heavy losses are experienced every year with shipments of boxed apples because of a peculiar type of injury that occurs in transit. The injury is most common in apples from the Pacific Northwest but has been found in those from Eastern States. It is more frequently seen and is sometimes more severe during the winter months than in the fall and spring. However, it has been observed on boxed apples shipped in the fall before freezing weather had occurred either in the producing regions or anywhere along the route taken by the shipment. It has also been seen so late in the spring that there was no possibility of the fruit having been exposed to freezing weather in transit.

In shipments of boxed apples the injury is usually found only in the fruit at the lower side of the bottom layer of boxes in the railway car, and for this reason is frequently thought to have been caused by freezing. Its occurrence in shipments arriving on the market during the period from December to March, inclusive, leads receivers to suspect freezing damage in the whole bottom layer of

[1] The writers are indebted to R. L. Newton and M. J. Payne, of the Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U.S. Department of Agriculture, for the construction of the apparatus used to simulate transit conditions.

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boxes and generally results in the sale of those boxes at a price substantially lower than that brought by the rest of the load. So common is it at times on eastern markets that it becomes an important factor in complicating the freight-claim situation among railroads, shippers, and receivers.

A condition similar to that found in boxes has also been observed just under the lids of bushel baskets and at various levels downward from the tail end of barrels. In general, in the latter case, the tighter the pack the farther down the injury is found in the barrel.

The form of the injury which is characteristic for barreled lots has been found (1) in York Imperial apples at the packing house 2 days after the barrels had been headed, and before even a light frost had occurred; (2) in Jonathan and King David apples, in New York City, after being unloaded from cars which moved from Virginia in September without transit refrigeration.

The following are the outstanding characteristics of the injury:

In boxed apples a flat bruised area is present on the side of the apple that was in contact with the lower side of the box as the latter lay in the car. The bruised spots have a water-soaked, darkened appearance, are generally quite firm, and may be an inch or more in diameter. Occasionally the skin covering them is discolored in spots or streaks, as shown in plate 1, B, or over practically all of the bruised area, as in plate 1, A. In cross section there is usually a water-soaked, glassy, wedge-shaped area which extends from the skin toward the center of the apple. This may be shallow or it may extend quite to the core. In some instances the inner edge of this area appears as a fairly smooth curve, concave toward the core; in others it is broken by strands or rays having the water-soaked appearance just mentioned and extending radially for as much as three fourths of an inch beyond the main affected area (pl. 1, C *a*, and D). Sometimes small water-soaked patches or streaks are also seen underneath bruises produced by the pressure of one apple against another, as shown in plate 1, C, *b* and *c*. Large bruised areas such as that shown in plate 1, A, are usually sunken, grayish or slate colored, and the flesh underneath them is rather soft.

In bruised apples from barrels and baskets, the bruised areas seen in cross section show a light-brown zone of fractured flesh underneath which there is frequently a more or less complete cone of glassy, water-soaked flesh almost identical in appearance with that described for boxed apples (pl. 2, A). It should be noted that the apple shown in plate 2, A, had not been exposed to freezing temperatures.

In barreled lots, the apples next to the lid at the tail end show the flat bruises, whereas those farther down show concave areas where one fruit has been squeezed against or into another. Both kinds are produced of course when the head is forced into place in closing the barrel. In all three kinds of packages—boxes, barrels, and baskets—fruits can practically always be found which show only the light-brown, shallow, so-called packing bruises in which the flesh is crushed or fractured (pl. 2, B and C), the lines of fracture running roughly parallel to the bruised surface, or concave away from it and parallel to each other.

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TYPICAL TRANSIT INJURY FOUND IN APPLE SHIPMENTS FROM THE PACIFIC NORTHWEST OR PRODUCED EXPERIMENTALLY.

A.—Exterior view of a Rome Beauty apple, showing severe transit injury in the form of a large, flattened, discolored, and water-soaked area. This apple was taken (in January) from the bottom layer of fruit in a commercially packed box which had lain on the false floor of a railway car during the transit period. There was no corrugated paper liner in the box.

B.—Exterior view of a Winesap apple, showing the same kind of injury as in A but in less pronounced form. The apple was taken from a commercial shipment in January. Note discolored streaks in the skin. No corrugated liner.

C.—Cross section of a Rome Beauty apple, from a commercial shipment in January, showing the transit type of injury *a* produced by pressure against the side of the box and two bruises *b* and *c* produced by pressure against other apples. No corrugated liner.

D.—Cross section of a Delicious apple, showing injury produced by jolting under pressure for four days at 70° F. No corrugated liner.

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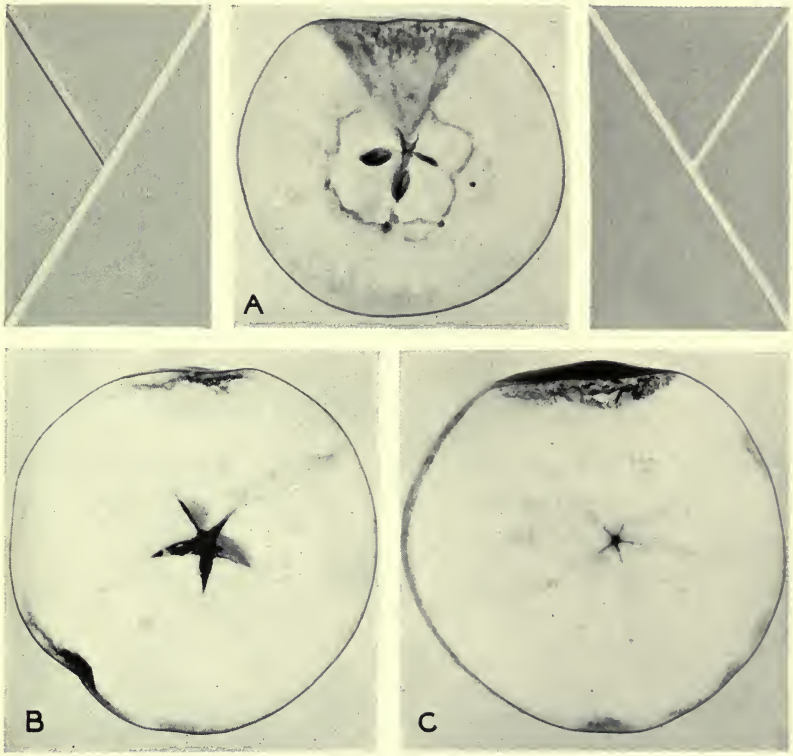

A, Cross section of a King David apple, showing a much flattened, bruised area in which a zone of browned flesh is present just under the skin, and below this is a conical water-soaked area extending to the core. This apple was taken from the tail end of a barrel which was unloaded in Jersey City, N.J., on September 17 after a 2-day journey from Front Royal, Va. The car was moved without refrigeration. B and C, Ordinary packing or handling bruises on Rome Beauty apples, showing lines of fracture in the flesh, most of which are roughly parallel to the surface of the bruised area.

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The glassy, water-soaked condition is commonly attributed to freezing in transit or in storage and has been the cause of much controversy among shippers, carriers, and receivers. Whether produced experimentally or observed in shipments of apples in railroad cars, it will be referred to in this bulletin as transit injury or the transit type of injury. The investigations herein reported were made in an effort to determine the cause of this condition and practical means by which it can be prevented.

HISTORICAL DATA

The effects of freezing on apples have been investigated by Carrick [2] and by Diehl and Wright,[3] but only under such conditions that while the fruit was freezing it was motionless and subjected to pressure. During both investigations, apples which had ice in their tissues were bruised, held for various lengths of time, and then allowed to thaw. They were then examined to determine the nature and extent of the injury produced.

Carrick [4] refers to a "darker triangular region shown in no. 4 [pl. III] and the three similar ones in no. 5" which were produced "by quickly applying a slight external force at these points while the fruit was still frozen." He also refers to a more severe form of the injury in which the triangular brown area extends to the core (his pl. VI, 1). He says;[5]

> The distinctive appearance of apples when sufficiently frozen and thawed, here assumed to be a manifestation of death, has been repeatedly designated by the terms *browning* and *discoloration*. In reality, the latter term often refers to some shade of brown or gray. The specific shade of color depends on the variety of apple, the severity of the injury, and the age of the lesion. These darkened areas, in whatever region they are observed, are usually water-soaked, and in less severe injury they appear somewhat translucent, as when ice is still present. When a large amount of tissue has been killed, the general effect is very suggestive of an overmature fruit which has become discolored in the absence of microorganisms.

Mention also is made of the frequent localization of browning in the fibrovascular bundles.

Diehl and Wright describe and illustrate much the same symptoms of freezing injury in apples as those described by Carrick, with a comment [6] that "bruises in hard frozen apples have a greater depth and are conical in shape with the apex reaching nearer to the middle of the fruit than on apples similarly bruised while unfrozen." They also note the condition in ordinary bruises mentioned earlier in this bulletin where lines of fracture appear approximately parallel to the surface.

In neither of the reports just discussed is there any description of an injury associated with freezing similar to the transit injury dealt with in this publication. The apple shown in plate 5, B, in the report by Diehl and Wright [7] has discolored areas in which there

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[2] CARRICK, D. B. SOME EFFECTS OF FREEZING ON MATURE FRUITS OF THE APPLE. N.Y. (Cornell) Agr. Expt. Sta. Mem. 81, 54 p., illus. 1924.
[3] DIEHL, H. C., and WRIGHT, R. C. FREEZING INJURY OF APPLES. Jour. Agr. Research. 29: 99–127, illus. 1924.
[4] CARRICK, D. B. Op. cit., p. 40.
[5] ——— Op. cit., p. 39.
[6] DIEHL, H. C., and WRIGHT, R. C. Op. cit., pp. 104–105.
[7] ——— and WRIGHT, R. C. Op. cit.

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are bands or streaks extending inward toward the center of the fruit. These streaks do not have the water-soaked appearance, however, that is described on pages 2 and 6 of this bulletin and shown in plates 1 and 2.

Zimmerman [8] described the transit injury seen in bottom-layer boxes of apple shipments arriving in New York and, so far as the writers are aware, was the first to call attention to the value of paper pads in preventing it. His description is as follows:

> The bruises are large, flat, in many cases discolored, and extend into the flesh of the apple for some distance. * * * If the fruit actually has been frozen, the bruises are deep, glassy, discolored, and the discoloration extends into the flesh in a pyramidal shape, whereas the bruises on apples which have not been subjected to freezing temperatures in transit may be badly discolored (especially on large ripe Romes or Delicious), but discoloration does not extend into the flesh to as great a depth.

Results reported later in this bulletin show, however, that glassy, discolored bruises extending deep into the flesh can be produced in apples at temperatures well above freezing and therefore are not necessarily a sign of freezing injury.

EXPERIMENTAL WORK

The apples used in this investigation were grown in the Pacific Northwest. They were secured in November and December 1930 and in January 1931 and 1932 from commercial lots that were in cold storage at the time or had just been removed from such storage. Immediately after being purchased they were placed at 32° F. and held there until needed for the tests. The fruit was carefully sorted before being used, and bruised specimens removed. In any one season it probably was somewhat riper and therefore softer in the later tests than in the earlier ones, and for that reason was fairly comparable to commercial lots inspected at various times in New York City during the season (winter of 1930–31) in which most of the tests were conducted (p. 12). Temperature readings were obtained by means of single-junction copper-constantan thermocouples, of the kind described by Taylor,[9] used in connection with a galvanometer and a potentiometer.

FREEZING POINTS OF BRUISED AND UNBRUISED PORTIONS OF APPLES

Early in the investigation it was thought possible that the pressure exerted on the bottom layer of apples in transit might have forced some of the cell sap into the intercellular spaces of the fruit and that the temperatures encountered were low enough to freeze the cell sap but not the pulp. Accordingly, freezing-point determinations were made on bruised and unbruised portions of apples. The results are shown in table 1. Although the average freezing point of the bruised portion was slightly higher than that of the unbruised portion, it hardly seemed possible that the small difference in freezing points (0.15° to 0.44° F.) was sufficient to cause one portion of the apple to freeze while the remainder did not. Furthermore, in some instances the unbruised portion of one apple froze at a higher temperature than the bruised portion of another apple.

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[8] ZIMMERMAN, F. PAPER PADS IN FRUIT PACKAGES. Better Fruit 24 (11): 10–11. 1930.
[9] TAYLOR, G. F. SOME IMPROVEMENTS OF THE NEEDLE-TYPE THERMOCOUPLE FOR LOW TEMPERATURE WORK. Jour. Indus. and Engin. Chem. 12: 797–799, illus. 1920.

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TABLE 1.—*Freezing points of bruised and unbruised portions of apples*

Variety	Average freezing point of bruised portions	Average freezing point of unbruised portions
	°F.	°F.
Rome Beauty	28.35	27.91
Stayman Winesap	28.93	28.66
Delicious	28.05	27.90

RATE OF COOLING OF APPLES IN THE BOTTOM LAYER OF A PACKED BOX

The rate of cooling in the upper and lower parts of individual apples in the bottom layer of a packed box of fruit was determined in order to find out whether it is possible for the lower part of the individual fruits to freeze while the upper part of the same fruits remains above the freezing point. The determinations were made after a box of fruit which had been held at 40° F. for a period of 6 days had been placed in a room held at 25°. This box was placed on a platform similar to the false floor used in a standard refrigerator car and was surrounded on the sides, ends, and top by other boxes of apples that had the same temperature. Just before freezing occurred the temperature of the bottom portion of the lowermost apples was 1° to 2.5° below that in the top portion of the same fruits, but freezing took place in all parts of an individual fruit at about the same time.

EFFECT OF FREEZING ON BRUISED AND UNBRUISED APPLES

Rome Beauty, Delicious, and Stayman Winesap apples, some of which had been purposely bruised, were subjected to a temperature of 21° F. for various periods up to 11 days in order to determine the relative effect of freezing on bruised and unbruised apples. In most cases a water-soaked area appeared under the bruises even after slight freezing. This injury apparently was not the same as the transit injury described earlier in this bulletin because the bruises characteristic of the transit injury are firm and darkened, whereas those produced in this experiment were soft and the only discoloration was a slight browning after freezing. Unbruised apples did not show injury until after prolonged freezing. In the Delicious only slight injury was noticeable on unbruised fruits after they had been frozen 3 days; Rome Beauty apples were very susceptible to freezing injury and the Stayman Winesaps were even more so.

EFFECT OF PRESSURE DURING AND AFTER FREEZING IN STATIONARY TESTS

In an attempt to determine the effect of pressure in producing the transit injury some stationary tests were conducted in which pressure equivalent to 10 pounds per apple was applied by weights. This is probably greatly in excess of the pressure sustained by an apple in a packed box. Pressure was applied to the apples (1) while they were freezing at 22° F., (2) while they were thawing, (3) while they were freezing and again while they were thawing, and (4) to unfrozen fruit held at 32°. The test included apples that were not bruised,

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as well as bruised apples with the weight resting on the bruise. The varieties used in these tests were Delicious, Winesap, and Yellow Newtown.

In no case was the typical transit injury produced. Pressure while the fruit was thawing resulted in more severe injury and more of the water-soaked appearance than was found under any of the other three test conditions. Although some of the bruises produced by pressure while the fruit was thawing became dark colored they were always soft, whereas those characteristic of transit injury were firm. The bruises were hardly visible in the fruit which was subjected to pressure but not frozen. Pressure applied only while the fruit was freezing produced very slight injury; bruising before pressure was applied increased the total injury slightly.

SIMULATING TRANSIT CONDITIONS IN THE LABORATORY

In an effort to simulate transit conditions, particularly the jolting to which shipments are subjected while being carried to market by rail, an apparatus was constructed, consisting of a small wagon that ran on a metal track and passed over wooden cleats five eighths of an inch high, 38 times a minute. The box held about 15 pounds of apples if the fruit was packed so that the lid when fastened in place had a pronounced bulge. Rome Beauty, Stayman Winesap, Delicious, Winesap, and Yellow Newtown apples were jolted in this apparatus for 48 to 72 hours at 22° F.; Winesap, Delicious, Stayman Winesap, and Yellow Newtown were run at 26° for 96 hours. Tests were also run with Delicious, Yellow Newtown, and Winesap at 35° and 65° for 3 days. In each test some of the fruit was wrapped, and some was not. A box of fruit similarly packed was held at each temperature—not jolted—as a check. About half of the fruit was bruised before being subjected to these conditions. All the fruit was examined for injury immediately upon removal from the apparatus and after being held at room temperature for 2 to 3 days.

In none of these tests was the typical transit type of injury produced. A water-soaked area extending from the bruise radially towards the core appeared in most of the bruised apples that were jolted and frozen and in some of the bruised apples that were frozen but not jolted. The water-soaked condition was more extensive where the bruise was in contact with the top or the bottom of the box. The bruised places, however, unlike those characteristic of typical transit injury, were somewhat soft and usually not discolored on the outside. Only a trace of the water-soaked condition appeared in Yellow Newtowns.

Some of the water-soaked condition was found in bruised apples that were jolted but not frozen; however, there was less of it in the nonfrozen fruit than in that which froze during the experiment.

Because of the failure of the apparatus described heretofore to reproduce the transit injury, a larger truck was constructed (fig. 1), which was capable of carrying 3 bushel boxes of apples with a 200-pound weight on each box.[10] This truck ran on a steel track

[10] Tests of this apparatus by means of an impact recorder kindly lent by the Fruit Growers' Express Co., of Alexandria, Va., showed that the jolting it produces is about the same as that to which shipments are subjected in the ordinary type of refrigerator car.

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and passed 38 times a minute over bolt heads projecting one fourth of an inch above the track. When the boxes with their weights were in place on the truck the whole load was wired down securely, to keep the shifting to a minimum. An extra board from the side of another apple box was placed between the weight and the top of each test box in order to distribute the applied weight as evenly as possible.

Northwestern-grown Delicious, Winesap, Esopus Spitzenburg, and Rome Beauty apples of medium size, commercially packed in standard bushel boxes, were used. The boxes were laid on their sides during these tests as they are when loaded into railroad cars. Unless otherwise specified there was no corrugated pad between the apples and the side of the box. The length of each test was approximately 92 hours. At 25° F., freezing started about 12 to 36 hours after the fruit was placed in this temperature.

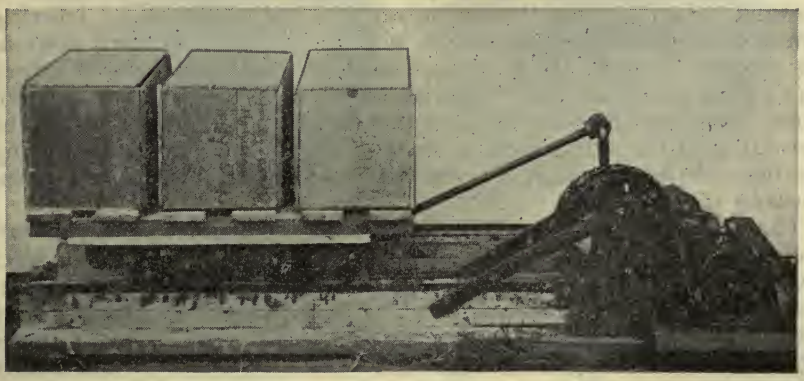

FIGURE 1.—Large apparatus used to simulate transit conditions.

The firmness of the fruit at the beginning of this series of tests, as determined by the pressure tester described by Magness and Taylor,[11] was as follows:

	Pounds
Rome Beauty	11.2
Esopus Spitzenburg	8.7
Delicious	9.0
Winesap	13.2

EFFECT OF JOLTING WITH AND WITHOUT PRESSURE AT FREEZING AND NONFREEZING TEMPERATURES

One box of each of the four varieties of apples was subjected to each of the following treatments:

Frozen; jolted; pressure.
Frozen; jolted; no pressure.
Frozen; not jolted; pressure.
Frozen; not jolted; no pressure.
Not frozen; jolted; pressure.
Not frozen; jolted; no pressure.
Not frozen; not jolted; pressure.
Not frozen; not jolted; no pressure.

[11] MAGNESS, J. R., and TAYLOR, G. F. AN IMPROVED TYPE OF PRESSURE TESTER FOR THE DETERMINATION OF FRUIT MATURITY. U.S. Dept. Agr. Cir. 350, 8 p., illus. 1925.

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"Pressure" means that a 200-pound weight was placed on the box, and wired down as already noted. The apples that were to be frozen were kept in a room held at 25° F. Those to be tested without freezing were subjected to a constant temperature of either 40° or 70°.

The typical transit injury described earlier in this bulletin, with the exception of the type of injury shown in plate 1, A, was produced in most of the bottom layer of apples in boxes that were jolted at 25° F., both with and without pressure. It was also produced in apples in the same position which had been given the same treatment except that they were held at 40° during the test; that is, under conditions where freezing could not occur. The injury was slightly augmented by freezing as well as by the application of a 200-pound pressure on the box.

The bruising produced by the jolting apparatus on Rome Beauty apples at freezing and nonfreezing temperatures is shown in plate 3. That produced on Esopus Spitzenburg under these conditions is shown in plate 4. The transit injury was not produced by freezing alone or by pressure on the boxes when the boxes were kept motionless during the test. In a subsequent experiment the typical injury was produced in all four varieties at 70° F., which is further evidence that low temperature is not a factor in producing it. The wrinkling of the skin noted on some of the apples that froze during the test (shown in pl. 3, A) was also seen on apples jolted at nonfreezing temperatures.

The results of these tests indicate that the transit injury is not necessarily due to freezing. When fruits from the various tests just described were compared, it was found impossible to distinguish the injury produced by jolting at nonfreezing temperatures from that produced by jolting at 25° F., except in a few cases where the bruised spots in apples that had frozen were noticeably soft.

The finding of transit injury in boxes of apples that were jolted at 25° and at 40° F. without pressure from the outside shows that the weight of the apples in a packed box furnishes enough pressure to cause the injury. As a matter of fact, the pressure on the bottom layer of apples in a packed box at the bottom of the load in a refrigerator car is probably not much greater than that produced by the weight of the apples in the same box, above the bottom layer, as compared with the actual weight of the boxes above. Information on this point was obtained by partly supporting a box of apples at the ends, the portion between being allowed to rest on the platform of a set of scales and the weight registered on the beam being noted, and then setting five packed boxes of apples on top of this box, and again noting the weight. All of the boxes were laid on the side, as is done when they are loaded into railroad cars. The pressure exerted on the scales by a single box whose ends were supported was 15 pounds; placing five additional boxes on top of this box resulted in 26 pounds of pressure on the scales, an increase of only 11 pounds, which is very much less than the weight of the added boxes. Rocking the boxes back and forth increased this pressure only slightly and of course only momentarily.

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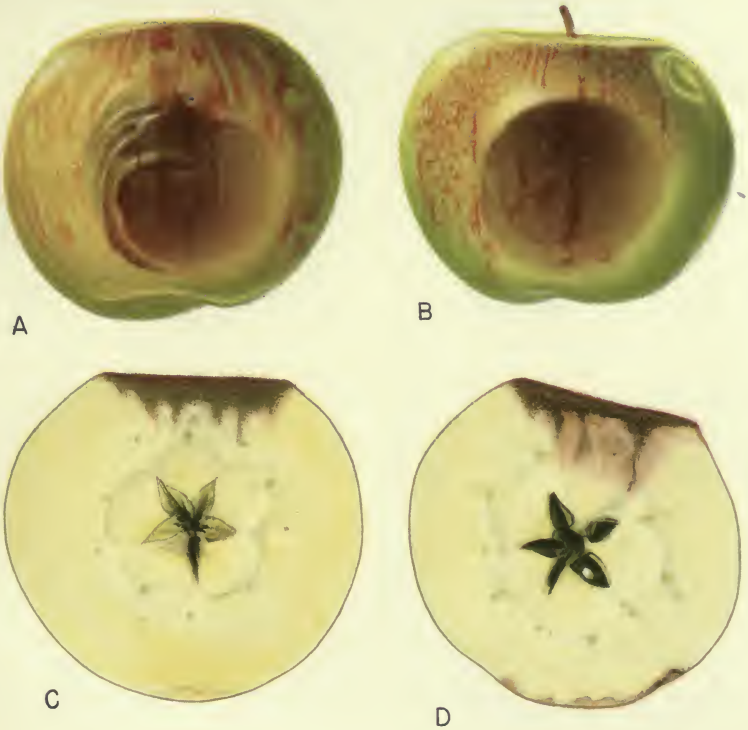

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TYPICAL TRANSIT INJURY IN ROME BEAUTY APPLES, PRODUCED IN THE LABORATORY BY JOLTING FOR FOUR DAYS UNDER PRESSURE IN A COMMERCIALLY PACKED BOX.

A and C.—Frozen. Temperature during the experiment, 25° F.
B and D.—Not frozen. Temperature during the experiment, 40° F.
No corrugated liners.

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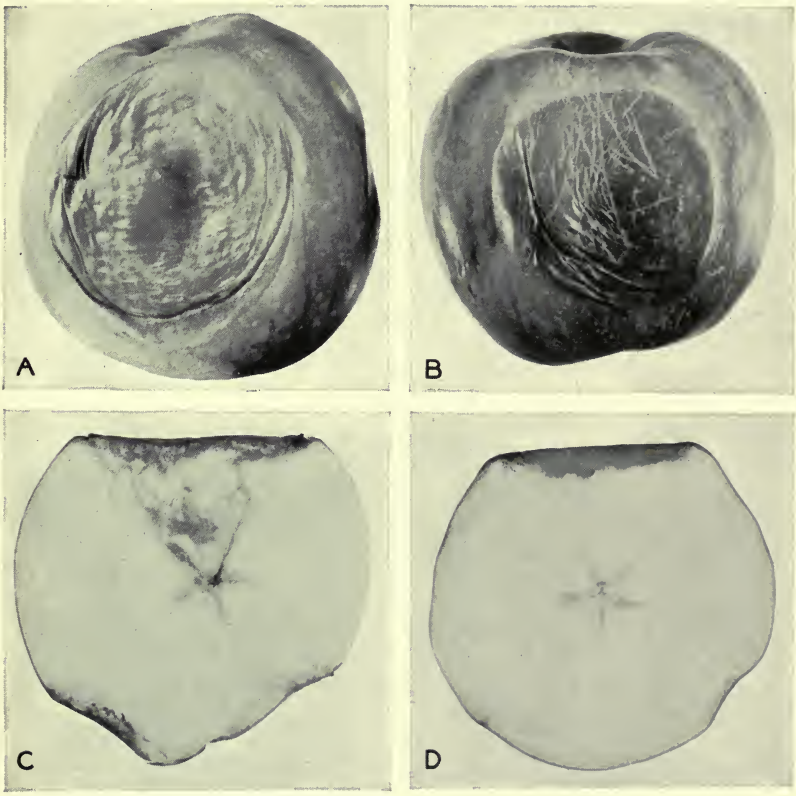

ESOPUS SPITZENBURG APPLES, SHOWING TRANSIT INJURY PRODUCED BY JOLTING FOR 4 DAYS.

A and C, Frozen; temperature, 25° F. B and D, Not frozen; temperature, 70° F.

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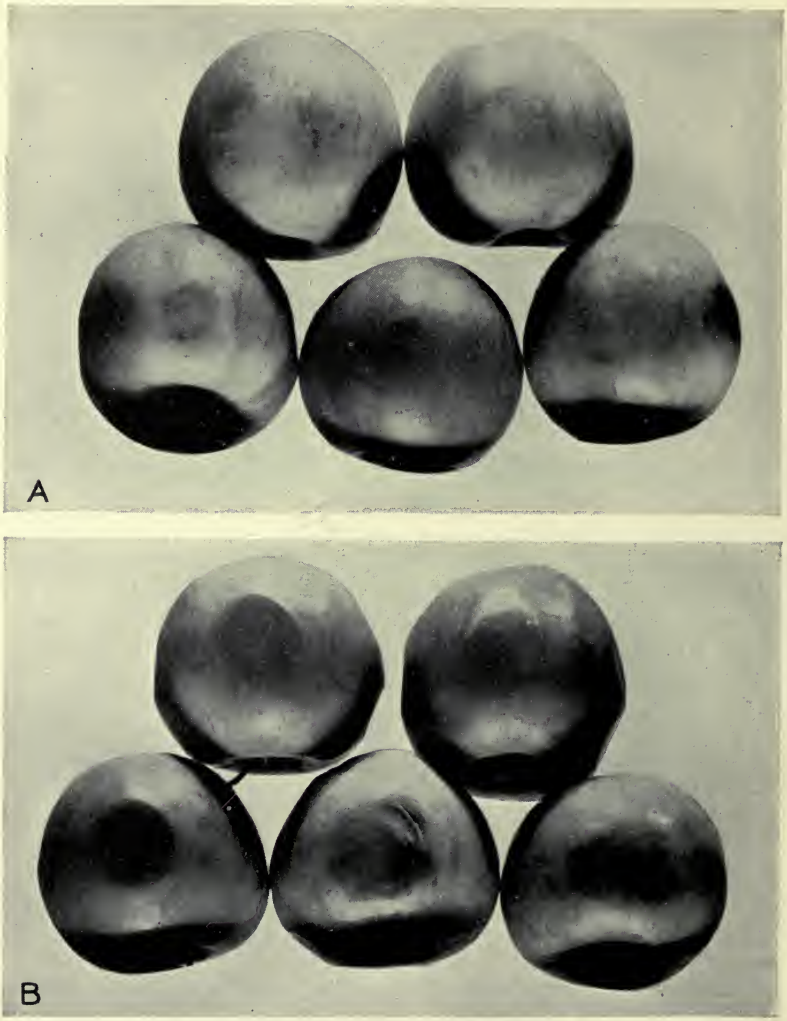

ROME BEAUTY APPLES SHOWING THE EFFECT OF JOLTING TWO COMMERCIALLY PACKED BOXES.

One box was placed directly on top of the other for 4 days at 25° F. The apples were taken from the bottom layers of the respective boxes. There was no pressure from the outside on the top box: A, From upper box; B, from lower box.

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Boxes of apples in a railroad car are subjected to more or less jolting while en route from shipping point to market, the severity depending on the speed of the train, the type of springs under the car, the smoothness or roughness of the track, the manner in which the cars are handled in starting or stopping the train and in switching operations, and on the length of the rail journey. It seems highly probable that the jolting received by the bottom layer of apples in the bottom boxes in a railroad car is sufficient to cause the transit injury here under discussion, without the fruit having been in a frozen condition at any time during the transit period. In this connection, it is worthy of particular note that in barreled apples (p. 2) the typical transit injury can be caused by pressure alone. In this case the pressure to which the fruit at the tail end of the barrel is subjected is undoubtedly much greater than that existing at any time in boxes of apples packed and handled in the ordinary commercial manner. In barrels a single heavy application of pressure produces practically the same injury as that produced in boxes by a long-continued application of a small amount of pressure.

COMPARISON OF FROZEN AND UNFROZEN APPLES IN THE SAME BOX

Apples when subjected to freezing temperatures remain undercooled below their freezing point for various lengths of time before freezing occurs, even when jolted.[12] This fact was made use of in an effort to determine definitely whether there is a difference in the appearance of apples that freeze while being jolted and of those that do not freeze under such conditions. Standard boxes of each of the four varieties were run on the jolting apparatus at 25° F., with thermocouples placed in the bottom portion of each of the apples in the bottom layer. Winesap and Esopus Spitzenburg were run without pressure on the box; a 200-pound weight was placed on each of the boxes of Rome Beauty and Delicious. These apples were jolted on the apparatus until about half of them were frozen; the remaining ones were still undercooled but had not frozen. At the end of the jolting period all of the fruit was removed and held for 2 to 3 days at 40°, in order to defrost the frozen apples, and was then examined.

Typical transit injury was found in both the frozen and the unfrozen fruit, but, with the exception of a few of the frozen apples in which the bruised area was somewhat soft, there was no apparent significant difference between the apples that had actually been frozen and those that had undercooled but did not freeze. In other words, the results are further evidence that freezing is not necessary for the production of the injury. An interesting point in this connection is illustrated in plate 5, B, which shows the water-soaked, glassy condition alongside the hole made in a Rome Beauty apple by inserting a thermocouple. Slight movement of the thermocouple in the flesh of the apple while the box was being shaken was apparently sufficient to produce the condition shown. In this instance the pressure against the flesh must have been very slight.

[12] LUTZ, J. M., and WRIGHT, R. C. STUDIES ON THE UNDERCOOLING OF CERTAIN FRUITS AND VEGETABLES UNDER EXPERIMENTAL TRANSIT CONDITIONS. Unpublished manuscript.

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EFFECT OF JOLTING ONE BOX DIRECTLY ON TOP OF ANOTHER

During this investigation the question was frequently raised, why apples in the lowermost layer of the bottom boxes in the car show the transit injury while apples in the same layer in boxes on top of these are injured less severely, if at all. If the injury were due to freezing it could be attributed to a temperature difference at various levels in the car sufficient to result in a localization of the injury near the floorboards, since it is a well-established fact that the temperature at the bottom of the load in a refrigerator car in transit is nearly always several degrees lower than that in other parts of the load.

In order to secure information on this point, one box of apples was placed directly on top of another on the platform of the jolting apparatus and wired in place. This test was run with all four varieties at 40° F. and with Rome Beauty, Delicious, and Winesap at 25°. The typical transit injury was produced at both temperatures in most of the apples in the bottom layer of the bottom boxes (pl. 6, B), whereas only a trace of it was found in apples similarly placed in the top box (pl. 6, A). The most plausible explanation for the difference is that the bottom box of apples absorbed the shock which produced the transit type of injury and did not transmit it to the upper box. If this is the true explanation it probably accounts for the prevalence of the transit injury in the bottom layer of boxes in a railroad car, even when some of the apples at that location do actually freeze, since the evidence already presented indicates that freezing alone does not produce the injury. It might be argued that injury appeared in the lower box and not in the upper one because of the extra weight on the apples in the lower box. Against this it is only necessary to refer to the evidence already presented (p. 8), that the injury can and does occur in jolted boxes which have no weight on top of them.

EFFECT OF PLACING STRIPS UNDER THE ENDS OF TEST BOXES

It was thought that resting the ends of the boxes on a wooden strip might be of some value in preventing the bruising injury. Accordingly, standard boxes of apples, the ends of which were supported by 1- by 2-inch lumber, were jolted on the apparatus at 25° and 40° F. with and without pressure applied from the outside. Under these conditions typical transit injury was produced in all four varieties, similar to that found in boxes not resting on strips. Plate 7 shows the condition of apples from boxes in which a corrugated paper liner was used and of apples from other boxes whose ends were supported by strips.

EFFECT OF STRIPS IN COMMERCIAL SHIPMENTS

During the winters of 1929–30 and 1930–31, about 20 shipments of apples in which the ends of the bottom layer of boxes were supported by strips were inspected in New York. Some of these had been prepared for test by the United States Department of Agriculture, and the others constituted part of an extensive series of tests inaugurated by one of the private car companies. It was found that the strips were of no value in preventing the transit injury.

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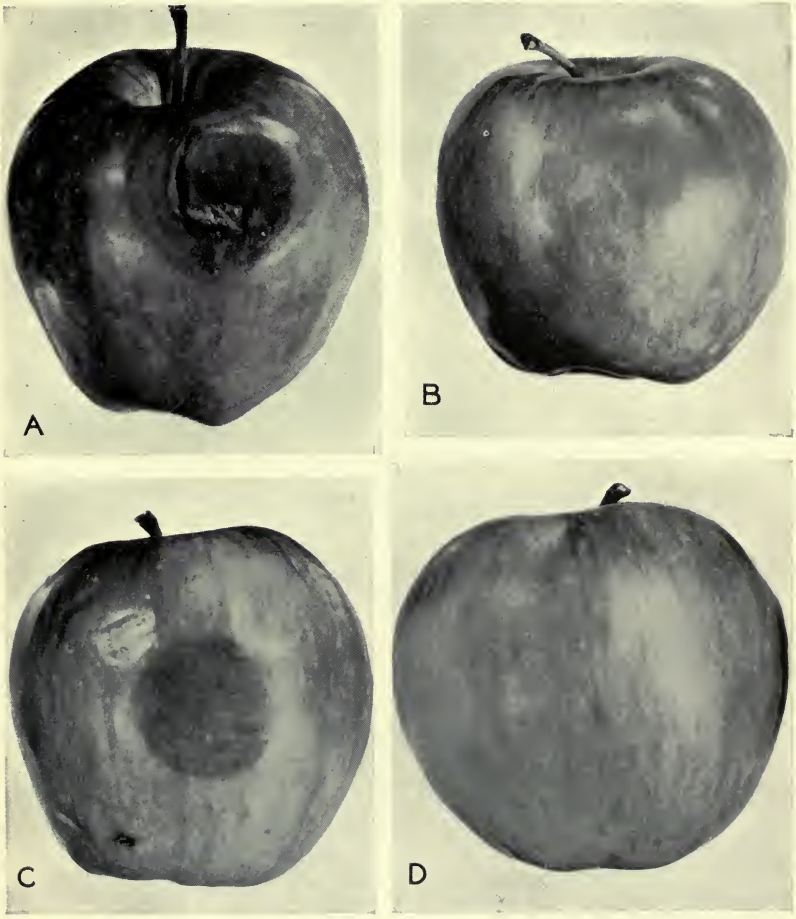

DELICIOUS APPLES JOLTED FOR 4 DAYS. APPLES TAKEN FROM THE BOTTOM LAYER IN THE BOX.

A, Ends of boxes supported by strips but no corrugated paper used; 25° F. B, Corrugated paper placed between the fruit and the side of the box; no strips under the ends of the boxes; 25° F. C, Same as A, at 40° F. D, Same as B, at 40° F.

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A, Rome Beauty apple, taken from a car unloaded in New York City on April 19, 1931, showing slight vascular browning in the deeper lying, browned portions of the injuries. Spots similar to these were found in ripe Rome Beauty apples subjected to jolting for 4 days at a temperature of 70° F. B, Longitudinal section of a Rome Beauty apple, showing a glassy, or translucent, water-soaked condition alongside of the hole made by thrusting a thermocouple into the flesh.

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In fact, when a box slipped endwise, as frequently happened, so that one end rested on the false floor instead of on the strip and the other end rested on a strip at an angle, worse bruising resulted than if the strips had not been used.

EFFECT OF PLACING CORK, LITH, AND CELOTEX UNDER THE BOXES

Sheets of cork, lith, and Celotex were placed on the platform, and boxes of fruit were placed directly on each of these materials to determine their effectiveness in absorbing shock sufficiently to prevent bruising injury. The cork and lith were 2 inches thick, and the Celotex was one half inch thick. Typical transit injury was found in apples in the bottom layer of all the test boxes placed on these materials.

EFFECT OF PLACING LITH UNDER THE SHAKING APPARATUS

In order to test the effect of a yielding roadbed, 2-inch sheets of lith were built up into a block 12 inches high, 2½ feet wide, and 7 feet long in a room maintained at a temperature of 40° F. The shaking apparatus was set on this block and a 4-day test was run with commercially packed boxes of Rome Beauty, Delicious, and Esopus Spitzenburg apples, the boxes being laid on their sides on the carriage of the apparatus. No corrugated-paper liners were used. After the completion of the test the lith was removed, the apparatus was placed on a concrete floor, and a second test was run with apples from the same lot as those used in the first test. An examination of the two lots showed that more of the transit type of bruising had been produced when the shaking apparatus rested on the concrete floor than when it rested on lith.

EFFECT OF A FROZEN AND AN UNFROZEN BASE UNDER THE SHAKING APPARATUS

About the middle of January 1932 two other tests were run, with the same varieties as in those just described. In the first test the shaking apparatus rested on a relatively dry, unfrozen mixture of soil and gravel about a foot thick, confined by a wooden form; during the second test the gravel and soil mixture was kept frozen by means of brine coils connected with a refrigerating system. The brine coils were not installed until after the first test.

The boxes were jolted under pressure for approximately 96 hours. Examination at the end of that time showed typical transit bruising on the lower side of the bottom layer of apples in all boxes of both tests. In other words, the condition of the experimental roadbed seemed to have little or no effect on the amount of bruising produced in the fruit. Whether this holds under actual transit conditions during the shipment of apples by rail is a matter for further investigation.

EFFECT OF CORRUGATED-PAPER LINERS IN TEST BOXES

In an attempt to find a means of reducing or eliminating the transit injury, various boxes of fruit were prepared for test by placing a single corrugated-paper liner between the fruit and the side of the box which was to lie on the platform of the jolting apparatus. The boxes thus packed were jolted for 92 hours at 25°

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and 40° F., with and without pressure. All four varieties were used. Inspection at the end of each test showed that there was much less of the bruising injury in the boxes containing corrugated liners than in those in which no liners were used. A slight amount of bruising appeared in some of the apples in boxes containing liners, especially when the fruit froze or had been subjected to the pressure of a 200-pound weight during the test, but it was far less serious than that occurring where the corrugated liners were not present. These results indicate that such liners would be an effective means of preventing bruising injury to apples under commercial conditions in transit, because of the protection they furnished against the injury under the extreme conditions to which the fruit was subjected on the jolting apparatus.

EFFECT OF CORRUGATED-PAPER LINERS IN COMMERCIAL SHIPMENTS

During the winters of 1929–30 and 1930–31, at least 50 shipments of apples in which the boxes either had been completely lined with corrugated paper or had corrugated paper next to the sides were inspected on the New York market. Some of these shipments were prepared for test by the United States Department of Agriculture, but most of them were ordinary commercial shipments. The transit injury was not found in any of the fruit in these cars but did appear, apparently in the form observed by Zimmerman[13] in 1930 and earlier, in fruit in the bottom layer of boxes from commercial shipments in which the corrugated paper liners had not been used. A few cars of apples were observed (prepared for test by the U.S. Department of Agriculture) in which the corrugated-paper liners were used in only part of the boxes in the car. Under such conditions the injury was not present in the bottom-layer boxes that had the corrugated-paper liners between the fruit and the side of the box, but did occur in the bottom-layer boxes that did not have such liners.

These observations and the results obtained with the jolting apparatus show the advisability of lining the sides of apple boxes with corrugated-paper liners if the bruising injury is to be avoided.

EFFECT OF CORRUGATED-PAPER PADS IN BARRELS

The failure of the pad to protect apples in barrels is undoubtedly due to the heavy pressure required to force the head into position. There is ample evidence at least that the fuller the barrel (and consequently the greater the pressure required in heading it), the greater is the damage from bruising.

Investigations made at a packing house at Hancock, Md., showed that when barrels are filled so that the apples stand an inch and a half above the top of the staves, about four times as much bruising is produced by the heading operation as when the apples come only to the top of the staves. In either case most of the severe bruises, if examined 2 or 3 days after the barrels are filled, show the water-soaked condition already described. After the fruit has been in headed barrels for a month, bruised spots on being cut no longer show the water-soaked condition but are dry and corky.

[13] ZIMMERMAN, F. Op. cit.

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EFFECT OF MATURITY OF THE FRUIT

During the latter part of the shipping seasons of 1929 and 1930 some of the transit bruises were rather soft in fruit in the more advanced stages of maturity. A similar condition was observed during the laboratory tests. It should be noted also that in tests with Rome Beauty apples which were eating ripe and were jolted with and without pressure, at temperatures of 40° and 70° F., a few bruises were found in which the flesh was brown throughout but not fractured; in the same lots of apples there were other bruises which had a quarter-inch layer of water-soaked flesh next to the skin, and underneath this was a brown zone of unfractured flesh one fourth to one half an inch deep. The latter is illustrated in plate 5, A. In both types of injury there was slight but distinct browning of the smaller vascular bundles. Both types are generally considered definite indications of freezing injury, but both were found in apples which could not have frozen during the experiment and were known to have been free of bruises at the beginning of the experiment. The bruises in which there was browning of the small vascular bundles were not restricted to the side of the apple which lay against the lower side of the box.

The wholly brown bruises with vascular browning just described had very much the appearance of those figured by Carrick on his plate III, 4 and 5.[14] When considered with the other results of this investigation, they justify the statement that the jolting of commercially packed boxes of apples at nonfreezing temperatures with or without pressure applied from the outside is able to cause all of the visible symptoms commonly recognized as characteristic of freezing injury, except the browning of the large vascular bundles near the core, the extensive killing of tissue mentioned by Carrick (see p. 3 of this bulletin), and the very large bruised areas similar to the one shown in plate 1, A. Such areas are gray or slate colored over nearly the whole surface; they are also noticeably sunken; and the flesh underneath them is rather soft. The injury, as already noted, usually occurs on the under side of the lowermost layer of apples in the box.

SUMMARY

A peculiar type of transit injury of apples is described which is found most commonly at the bottom of loads of boxed apples in railroad cars.

A description is also given of a somewhat similar type of injury found in barrels and baskets of apples when considerable pressure has been used to force the head or the cover into place.

The occurrence of the injury cannot be ascribed to the small difference in freezing point of bruised and unbruised portions of the apples or to the difference in the rate of cooling of the upper and lower portions of individual apples.

Attempts to produce the injury in stationary tests were unsuccessful.

The typical transit injury was produced at freezing and nonfreezing temperatures by simulating transit conditions; that is, by jolting apples in commercially packed boxes, with and without pressure

[14] CARRICK, D. B. Op. cit.

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from the outside. The only visible symptoms of true freezing injury which have not been produced by this treatment are the browning of the large vascular bundles, usually 10 in number, around the core, the extensive killing of tissue found in severely frozen apples, and the large gray or slate-colored sunken areas similar to the one shown in plate 1, A.

It is impossible to distinguish the transit injury produced at freezing temperatures from that produced at nonfreezing temperatures except in occasional fruits in which the bruised area becomes somewhat soft after having been frozen. However, this softening is sometimes found in bruises on fairly ripe fruit which has been bruised while not frozen.

Corrugated-paper liners placed next to the sides in boxes of apples eliminated practically all of the bruising or transit injury both in the laboratory and under actual transit conditions. Wooden strips placed under the ends of the boxes were of no value in preventing the injury in the laboratory tests or under actual transit conditions. In barrels, the placing of a corrugated-paper pad on the fruit after the barrel is filled but before it is headed up seems to have no effect in preventing bruising and the transit type of injury.

Cork, lith, or Celotex placed under the bottom layer of boxes were of no value in laboratory tests in preventing the transit type of bruising.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

THE EFFECT OF DIFFERENT COLLOIDAL SOIL MATERIALS ON THE EFFICIENCY OF SUPERPHOSPHATE

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INTRODUCTION

Comparatively little is known of how different soils affect the efficiency of superphosphate. Numerous practical experiments such as those determining the comparative values of different phosphatic fertilizers have thrown little light on the subject. In most such experiments, no value for the efficiency of superphosphate is obtained that can be fairly compared with that obtained in another soil. More intensive experiments involving determinations of the phosphoric acid recovered in the crop show that some soils must affect the efficiency of superphosphate profoundly, since the proportion of applied phosphoric acid recovered in the crop is frequently only 10 to 20 percent (*26*, *39*),[1] as compared with 90 percent and 60 percent recoveries of nitrogen and potassium (*50*, *51*). But experiments of this kind have not furnished comparable figures for a wide variety of soils, since utilization of the applied phosphoric acid varies with the kind of crop and is affected by varying climatic conditions as well as by the character of the soil.

Laboratory studies of the fixation of phosphoric acid by soils have been made in great numbers since Warington (*52*) investigated the subject in 1868. These experiments by themselves are inadequate

[1] Italic numbers in parentheses refer to Literature Cited, p. 36.

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to show how the efficiency of superphosphate for crops is affected by soils, since laboratory methods of determining the availability of the fixed phosphoric acid at best only approximate the plant's capacity for assimilating phosphoric acid. But some of these studies throw light on results obtained in vegetative experiments with plants, and these are discussed later.

The study of soil colloids has suggested to several investigators (*18*, *23*) that the efficiencies of different phosphatic fertilizers may be largely affected by the colloidal soil material. Experiments have already been conducted with artificial iron, alumina, and silica gels, which are presumably similar in some respects to the colloidal material of the soil. Years ago Prianischnikow (*40*) showed that the addition of hydrous ferric oxide to sand cultures depressed the efficiency of bone meal for barley, and Pfeiffer and Blanck (*38*) showed that a mixture of alumina and silica gels depressed the efficiency of potassium acid phosphate for yellow lupines. More recent experiments by Lemmermann and Wiessmann (*31*), Gile and Smith (*23*), and Jessen and Lesch (*29*) showed that colloidal silica may increase the efficiencies of various phosphates including superphosphate.

This investigation was undertaken with the idea of determining how the efficiency of superphosphate as a fertilizer is affected by a number of natural, widely different, colloidal soil materials.

PLAN AND METHODS

The comparative effects of different soil colloids on phosphate utilization by the plant was investigated by means of vegetative experiments in sand cultures involving some 1,400 pots. In order to limit the study, only one kind of crop, millet, was grown, and practically all the work was conducted with one phosphatic fertilizer, superphosphate.

Before it was possible to determine the conditions that would give a fair comparison of different colloids, it was found necessary to study the following subjects: Modifications of the base fertilizer used with superphosphate; method of applying the superphosphate; effect of the soil on superphosphate as influenced by quantity of soil, by quantity of phosphate, and by reaction of the medium; the effects of colloidal and noncolloidal fractions of the soil. Information was also obtained regarding the effect of an artificial colloid, activated charcoal, on the efficiencies of superphosphate and ground rock phosphate, and regarding different methods of calculating fertilizer efficiencies.

The data of the different experiments, some of which bear on more than one of the above-mentioned subjects, are shown at the end of this report; the summarized results are given under the various headings.

The general plan adopted for experiments designed to show the effect of a soil colloid on superphosphate efficiency called for one series of pots containing pure quartz sand and another series filled with a mixture of sand and soil, the soil being applied at a rate to furnish about 1 percent of colloidal material.

All pots received the same base fertilizer which was designed to supply all essential nutrients in excess, except phosphorus. The pure quartz-sand series was installed as a basis for comparison. It received increasing quantities of superphosphate, and the efficiency

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of the superphosphate in this nonreactive medium, lacking colloidal material, was taken as 100 percent. From the results of this standard series a curve was plotted showing the increased growth to be attained, under the experimental conditions, with any quantity of P_2O_5 below the maximum. In the soil-sand series some pots received no phosphate, and others received a quantity of phosphate less than the optimum. The yield of the no-phosphate pots, which received some phosphoric acid from the added soil, was subtracted from that of the phosphate pots to give the yield attributable to the superphosphate application.

The efficiency of the superphosphate in the soil-sand mixture is calculated against the assumed 100 percent efficiency in pure quartz sand, on the basis of the comparative quantities of superphosphate required to produce the same increased yield in the two mediums. The quantity of phosphoric acid that gives the same increase in pure sand as that actually obtained in the soil-sand mixtures is found by consulting curves plotted for yields of the pure-sand series. The ratio of these two quantities of phosphoric acid times 100 gives the efficiency of superphosphate in the sand-soil mixture, as a percentage. The advantages of this method of calculating efficiencies have been pointed out in a previous publication (*20*). Theoretically, the dry weight of the crop is adequate data for calculating efficiencies by this method, and determination of the quantity of P_2O_5 recovered in the crop is unnecessary. However, some 70 of the crops were analyzed, and a comparison was obtained of efficiencies based on the two kinds of data. This is discussed under a subsequent heading. Unless otherwise specified, efficiencies reported in the following tables were based on the oven-dry weights of the crops.

This method of measuring the influence of soil colloids on phosphate efficiency assumes that the soil or soil colloids affect growth only by affecting the phosphate. Obviously, this is true only within limits. It is quite conceivable that the addition of soil or soil colloidal material might in some cases reduce the availability of nutrients added in supposed excess to a point where they, rather than the phosphorus, would be in minimum. The soil could also provide elements affecting growth that were not present in the simple quartz medium. The hydrogen-ion concentration of the medium is in most cases altered somewhat by the addition of soil; likewise, the water relations, probably the microorganisms, and the protection of roots against injury from salt concentrations are affected by the addition of colloidal soil material.

As a matter of fact, a few cases were encountered in this work where some of these possible effects of soil additions were operative to such an extent as to render impossible or inaccurate the proposed method of measuring phosphate efficiency. The addition of Fallon soil, for instance, in one experiment (table 16) [2] rendered iron so unavailable in the soil-sand medium that millet showed a marked chlorosis and growth was reduced more by lack of iron than by lack of phosphorus. In another experiment (table 30) the peat of pH 3.5 rendered the peat-sand mixture so acid that growth with the given amount of superphosphate was doubtless less than it otherwise would have been, and the influence of the peat on phosphate efficiency was obscured.

[2] Tables 11 to 31 appear in the Appendix.

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However, so long as the quantity of phosphate supplied was kept in minimum these secondary effects of the colloidal material were, except as noted, of negligible importance as compared with the effect on the phosphate. It is evident from results obtained in experiments reported in tables 17, 21, and 22 that the quantity of phosphorus available to the plant was the factor controlling growth in this work. In these experiments the addition of Nipe soil and of Sassafras and Clarksville subsoils reduced yields markedly below those of corresponding pots in the pure quartz-sand series when the quantity of superphosphate applied was small, but when sufficient superphosphate was supplied the yields in some cases became even greater than those in the sand series.

In only four of the experiments described here was the extracted colloidal fraction used in the sand cultures; in the other experiments the whole soil was added to the sand in an amount sufficient to supply the desired quantity of colloidal material. It would seem, therefore, that this work was largely a study of the effect of the whole soil on phosphate efficiency rather than a study of the colloidal material, unless it were assumed that the noncolloidal part of the soil was without influence on phosphate utilization. This last assumption appears valid, except for soils containing noncolloidal carbonate of lime, since it is evident from previous work (*3*) that distinctively mineral, noncolloidal soil particles have slight reactivity as compared with the colloidal soil material. However, direct evidence as to the comparative effects of colloidal and noncolloidal soil fractions was obtained in four experiments described later. This work cannot be discussed in detail at this point, but the results indicate that the procedure of adding the whole soil to the sand on the basis of colloidal content may give fully as fair a comparison of the effects of different soil colloids as the use of extracted colloidal fractions. Either method is open to some objection.

Details of the procedure followed in conducting the tests are given below.

Glazed earthenware crocks of 1-gallon capacity were used as containers. Each pot was filled with 5,000 g of quartz sand, or 5,000 g of sand and soil.

A uniform mixture of the soil or superphosphate with the sand was obtained by moistening the sand with about 1 percent of water to prevent segregation of materials. The superphosphate applications were mixed with small quantities of sand or soil prior to being mixed with the bulk of the material.

The base fertilizers used in different experiments are shown in table 1. They were added to the pots in solution before planting. In some experiments conducted during periods favorable to rapid growth, a further application of nitrogen and potassium (base fertilizer no. 9) was added to all pots when the nitrogen was nearing exhaustion in the pots carrying the greatest growth. Experiments in which this supplementary fertilizer (no. 9) was applied are noted in table 1.

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TABLE 1.—*Composition of base fertilizers used in the different experiments*

Base fertilizer no.	$Ca(NO_3)_2.4\ H_2O$	$(NH_4)_2\ SO_4$	KCl	$MgSO_4.7\ H_2O$	$Fe_2(C_4H_4O_6)_3.H_2O$	$MnSO_4.2\ H_2O$
	Grams per pot	*Grams per pot*	*Grams per pot*	*Grams per pot*	*Grams per pot*	*Grams per pot*
1	1.070	0.491	0.446	0.914	0.074	0.033
2	.535	.31	.338	.457	.0185	.0017
3	.535	.31	.338	.457		
4	.535	.31	.338	.457	.037	.0017
5	.202	.31	.125	.33	.0185	.0017
6	.535	.31	.338	.457	.0185	.0017
7	.552			.457	.0185	.0017
8	.552			.457	.0185	.0017
9		.155				

Base fertilizer no.	KNO_3	NaCl	$CuCl_2$	H_3BO_3	Total salts less water crystallization	Concentration total salts	Table in which use of fertilizer is reported
	Grams per pot	*Grams per pot*	*Grams per pot*	*Grams per pot*	*Grams per pot*	*Parts per 1,000 of H_2O*	
1					2.23	2.79	11.
2					1.26	1.58	All except 11.
3					1.24	1.55	12.
4					1.28	1.60	12.
5	0.295				1.05	1.31	12.
6		0.131			1.39	1.74	14.
7	.462	.131			1.22	1.53	14, 29.
8	.462	.131	0.0008	0.0074	1.23	1.54	14.
9	.232				.387	.48	12, 16, 17, 19–23, 29, 31.

German, or foxtail, millet (*Setaria italica*) seed were planted, and as the seedlings became established they were thinned to 10 plants per pot.

The pots were kept in a glasshouse, the temperature of which varied from about 75° in winter to 110° F. on hot days in early summer. The position of the pots relative to one another was changed daily, except Sunday, in a regular manner. The water content of the sand, determined by weighing the pots, was kept at approximately 17 percent by the addition of distilled water.

In winter months the plants were grown until heads began to appear. At other times of the year they were grown until a shortage of nitrogen developed in the high-phosphate pots of the check series, as indicated by yellowing of the lowest leaves. The duration of the experiments varied from 20 to 50 days, depending on temperature and light relations.

Only the plant aboveground was harvested. The oven-dry weights reported were obtained by first thoroughly air-drying the crop and then drying for 2 hours at 105° C.

Replication of the treatments varied somewhat in different experiments to conform with the accuracy desired and the number of treatments in the experiment. In experiments involving a few pots, less replication was needed to attain a given accuracy than in experiments involving a greater number. Apparently this was owing to the fact that conditions in the glasshouse were more uniform in a small space than in a large one. Usually all treatments were replicated four times. However, as the work progressed and uniform lots of sand lacking in phosphorus were obtained, it became evident that it was not necessary to replicate the no-phosphate treatments, since growth

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here was so slight, about 0.1 g of dry matter per pot, that an exact determination of this quantity was unessential.

SOILS AND MATERIALS

The quartz sand used in this work was a commercial grade of "glass sand." It contained no soil or clay, but one lot, used in experiments reported in tables 11 and 16, contained enough soluble alkali to impart a hydrogen-ion concentration of 7.5 to the material with fertilizer salts added, and another lot was evidently contaminated with some phosphate, as shown by the results of experiments reported in tables 13, 17, and 23. That used in the other experiments was apparently free from impurities affecting plant growth, and did not change the hydrogen-ion concentration of distilled water appreciably.

Seventeen surface soils, 14 subsoils, 2 peats, and 3 activated charcoals were tested for their effects on the efficiency of superphosphates. With two exceptions, the soils were taken from the collection of soils from different parts of the United States utilized in the colloid studies described in previous publications. The location of the soils and the chemical composition of the whole soil and of the colloid present are given in a previous bulletin (*44*). The adsorption and other properties are also described in previous publications (*22*, *4*).

The Brazil soil was a surface sample taken from a coffee plantation in Sao Paulo, Brazil. It is not an authentic sample of a well-defined soil type, but it was used in this work as the colloidal material had a very low silica sesquioxide ratio. It contained about 66 percent of colloidal material as ascertained by the water-adsorption method (*43*). The analysis of the colloid is given in table 2.

TABLE 2.—*Chemical composition of colloids extracted from the Nipe and Brazil soils* [1]

Name of colloid	SiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	MnO	CaO	MgO
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Nipe	12.48	17.93	52.92	0.67	0.69	0.33	0.12
Brazil	24.23	34.10	21.86	----------	.18	.45	.07

Name of colloid	K_2O	Na_2O	TiO_2	P_2O_5	SO_3	Mols $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	
Nipe	0.34	Trace	0.64	0.06	0.02	0.41
Brazil	.28	do	1.82	.23	.13	.85

[1] Analyses by G. Edgington.

The lot of Nipe soil was of the same type as that described in a previous bulletin (*1*) but was a new field sample. The analysis of the colloid is given in table 2. The colloid content of the soil was 66 percent as ascertained by the water-adsorption method.

The quantities of colloidal material present in the different soils were calculated in most cases from data regarding adsorption of water and dye, given in a previous publication (*22*). In a few cases this was supplemented by later data as to the quantity of colloid actually isolated, or the quantity of water vapor adsorbed by the soil over 3.3 percent by weight sulphuric acid. Before being used in the pot

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experiments, the soils were passed through a ½-millimeter sieve to promote intimate mixture with the sand and phosphate.

The same sample of superphosphate was used in all the following experiments. It contained 18 percent available P_2O_5 and was ground to pass a 150-mesh screen before being mixed with the soil or sand.

The rock phosphate used in a few experiments was a Tennessee brown-rock phosphate, ground to such fineness that 78.3 percent passed a 300-mesh screen and 99.7 percent passed 100 mesh. The total P_2O_5 content was 33.73 percent.

The physical characteristics of the two peats used in the experiment reported in table 30 have been described by Feustel and Byers (*13*). The one of pH 5.8 was a saw-grass peat from Clewiston, Fla., 10 to 16 inches in depth; and the peat of pH 3.5 was the 24- to 30-inch layer of a sedimentary peat from Beaufort, N.C.

Charcoals applied in experiments reported in tables 30 and 31 were prepared from activated charcoal supplied by the Chemical Warfare Service. As received, the activated charcoal contained considerable ash, including phosphorus and iron, but a lot of this was purified to give "charcoal of pH 4.1" in the following manner: About 1 pound of charcoal was boiled with 5 successive 1,500-c c portions of 10 percent hydrochloric acid. It was then washed with 1,800 c c of H_2O 23 times, the water being removed each time by suction through a clay filter. The charcoal was then treated twice with 1,500-c c portions of normal NaCl to facilitate removal of acid and then washed with 1,800-c c additions of water 32 times. The last washings had a pH of approximately 4.1 and gave no test for chloride.

Charcoal described as "charcoal pH 4.3" was prepared in the same manner except for variations in quantities of sample, water, etc. The lot designated as "charcoal of pH 9.6" was also prepared similarly, except that preceding the treatment with normal NaCl the sample was treated with 1,000 c c of 10 percent sodium hydroxide. The treatment with sodium hydroxide released large quantities of chloride which must have been closely held by the charcoal, since preceding the treatment with alkali the sample had been washed 30 times with water and the last washings gave only a weak test for chloride.

EXPERIMENTAL RESULTS

The results of the various experiments are shown in tables 11 to 31. Figures given for the efficiency of superphosphate are based on the weight of the crop in all cases where the content of P_2O_5 is not mentioned. In order to condense the data, the yields of individual pots are omitted, and only average yields are shown, together with the probable error of the average. The probable error, calculated by the formula $P.\ E. = 0.6745\sqrt{\frac{\Sigma d^2}{n\ (n-1)}}$, is given more as a short method of showing all the data obtained than as a strict measure of accuracy. In these experiments the variation of duplicates seemed to be determined largely by the position of the pots in the greenhouse during early growth. Such being the case, the average figure for variable duplicates in fairly distributed locations might be practically as accurate as the average figure for closely agreeing duplicates exposed to uniform conditions, although the probable errors would be very different in the two cases. Probably the Student method of

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calculating probable error would give a fairer estimate of accuracy in these experiments than the usual method.

THE BASE FERTILIZER

It was desirable that the base fertilizer used in this work should give both a good growth in pure quartz sand and a high availability of the superphosphate. There are grounds for believing that these two qualtities, in their highest development, may be incompatible in the same fertilizer, since the base fertilizer giving the greatest growth in sand with excess phosphate would probably give a small increase per unit of phosphate, in other words, a low availability of the phosphate. But a fertilizer was finally adopted which seemed to satisfy both requirements fairly well.

In the first experiment (table 11) trial was made of a base fertilizer that was similar, except for addition of $MnSO_4$, to a fertilizer used in a previous study with fairly satisfactory results (*23*).

The composition of this fertilizer is shown in table 1, under the heading no. 1. Growth with this fertilizer was hardly satisfactory, as the seedlings seemed to be somewhat slower in getting established in the pure sand cultures than in the series containing soil. This was thought to be owing to too high a concentration of salts. Also, it was apparent from the results of the experiment shown in table 11 that the quantity of manganese used in the base fertilizer markedly cut down the efficiency of the smaller superphosphate application.

An experiment (table 12) was then conducted with salt mixtures (nos. 2, 3, 4, and 5 of table 1), which were much lower in manganese and contained only about one half the salts per pot as the preliminary fertilizer. The quantities of iron, manganese, calcium, and magnesium were varied in these fertilizers, to learn whether the quantities applied affected the efficiency of superphosphate in pure quartz sand. The results of this experiment (table 12) showed that there was little to choose between the fertilizers in their effects on superphosphate, except that no. 4, with the high iron, was inferior. Fertilizer no. 2 was therefore used in further experiments.

With these smaller quantities of fertilizer, growth seemed perfectly satisfactory, but it was observed in subsequent experiments that plants in the soil-sand mixtures usually gained a slightly better start than those in pure sand, although the ultimate growth was much less. The ratio of salts to water in these experiments was only about one fourth that used by Ayres (*6*) in his study of sand cultures.

It was thought that this better start might be connected with the acidity of the medium. An experiment (table 13) was therefore conducted to ascertain whether the quartz-sand medium and base fertilizer could be improved by the addition of calcium carbonate. Precipitated calcium carbonate was used, and this was mixed uniformly with the sand. The early growth of the plants was about the same in all the pots, but in later growth the following significant differences developed. The carbonate additions markedly depressed the growth made with the smaller applications of superphosphate; growth with 0.12 g of P_2O_5 was greatest in the series receiving 0.4 g of $CaCO_3$; and a chlorosis became most pronounced in the series receiving 1.6 g of $CaCO_3$. Apparently the addition of 0.4 g of $CaCO_3$ lowered the availability of the superphosphate, while it rendered the medium somewhat more favorable for growth with an excess of superphosphate.

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The 1.6 g of $CaCO_3$ not only lowered the availability of the superphosphate, but it diminished the availability of iron to such an extent that a good growth could not be attained with a heavy application of superphosphate. It thus seemed that even small additions of lime to the base fertilizer would be of doubtful value.

A trial was then made to find whether the base fertilizer could be improved through additions of sodium, copper, and boron, or through a change in the hydrogen-ion concentration brought about either by the use of sodium bicarbonate or by supplying the nitrogen all as nitrate rather than one half as nitrate and one half as ammonium sulphate. The salt mixtures used were nos. 2, 6, 7, and 8 of table 1, and the results of the experiment are shown in table 14. Obviously, the addition of sodium, copper, and boron did not improve growth in the sand cultures well supplied with superphosphate; probably sufficient of these elements, if needed, was present as impurities picked up from containers used for sand and water and from the superphosphate and other salts applied. Even the small application of sodium bicarbonate was plainly injurious, and the substitution of all nitrate for one half nitrate and one half ammonia was unfavorable also.

The addition of Sharkey soil, which increases superphosphate efficiency, did not increase growth in the acid medium afforded by one half NO_3 and one half NH_4; but it increased growth in the all-nitrate medium. Possibly the phosphate supply was somewhat below optimum in this slightly alkaline medium, and the Sharkey soil added some available phosphate.

No further modifications of base fertilizer no. 2 were attempted, and this was used as the standard in subsequent experiments. It was found later that the slightly better start of plants in the soil-sand mixtures than in the pure sand cultures was probably due to the colloidal material protecting the young seedlings from temporary unfavorable concentrations of salts near the surface when the seedlings were getting a start. This was largely overcome by special care in watering during that period.

When, in the early part of this study, it was found that the addition of certain soils to quartz sand rendered small quantities of superphosphate almost entirely unavailable, it was suspected that such a pronounced effect might be abnormal. Since the concentration of salts in the pot cultures was greater than would be encountered under ordinary field conditions, it was thought that the base fertilizer might have in some way activated the reaction of the soil with the phosphate. Mattson (*32*), for instance, has shown a marked solubility of the iron and aluminum of colloidal soil material after treatment with concentrated solutions of ammonium chloride. In water cultures, however, where no soil is present, the concentration of salts has little effect on the absorption of phosphates by plants, according to Breazeale and McGeorge (*9*).

Accordingly, an experiment was conducted in which half the normal quantity of the standard base fertilizer (no. 2, table 1) was compared with the usual application. Owing to the small quantity of nutrient salts applied to part of the pots, the plants were grown to only about one half the usual size. The results of the experiment (table 15) show that the soil addition depressed growth to just as great an extent with half the base fertilizer as with the full application. It is also

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evident from the growth made with the two fertilizers in pure quartz sand that the concentration of the standard fertilizer was favorable for growth.

METHODS OF APPLYING SUPERPHOSPHATE

In a preliminary experiment (table 11) application of the superphosphate in a layer 1 inch deep, about one fourth inch below the seed, was compared with applications mixed uniformly with the whole mass of sand, or sand and soil. In the soil-sand mixture the soil, as well as the phosphate, was confined to a 1-inch layer. A marked difference was observed between the two methods of application, and further tests were conducted in experiments described in tables 12, 16, and 17. The results obtained are summarized in table 3. In all cases, except one, there is a distinct difference in favor of the layer application, but the difference is especially marked in the soil-sand mixture.

TABLE 3.—*Summary of results obtained on comparing applications of superphosphate and soil in layers with applications uniformly mixed with all the quartz sand* [1]

Conditions of comparison			Efficiency of application in a layer [2]	Efficiency of corresponding application uniformly mixed [2]
Kind of soil added to quartz sand and the quantity, expressed as grams, of colloid present	Kind of base fertilizer used	P_2O_5 applied per pot		
		Gram	*Percent*	*Percent*
None	No. 1, high Mn	0.04	332	100
	do	.12	168	100
	No. 2, standard	.06	120	100
	No. 3, Fe and Mn omitted	.06	150	100
	No. 4, double Fe	.06	97	87
	No. 5, Ca and Mg reduced	.06	120	97
	No. 2, standard	.06	95	100
Nipe, 50 g	No. 2, standard	.12	42	10
Brazil, 50 g	No. 1, high Mn	.12	123	13
Cecil subsoil, 50 g	No. 2, standard	.06	60	14

[1] Data obtained from tables 11, 12, 16, and 17.
[2] The superphosphate is assumed to be 100 percent efficient where it was uniformly mixed with all the sand and the standard base fertilizer no. 2 was used.

The results show the necessity of using great care in applying the phosphates in the following tests on the effects of different soils on phosphate efficiency. It was thought best in all this work to adopt the method of mixing the phosphate and soil uniformly with the whole quantity of sand. This method was expected to give more uniform results in the pure sand cultures, and it would hardly be advisable to confine the soil to a layer in the soil-sand cultures, since the physical condition of this layer would be quite different when different soils were used.

The favorable effect of the layer application is probably due in part to the plants obtaining a quicker start through the increased quantity of phosphate within reach of the first roots. There was about five times as much phosphate per unit volume in the layer as in a similar zone of the sand receiving the uniform application. The fact that when the comparison was conducted in pure quartz sand the difference in favor of the layer application was considerably greater during early growth than it was when the plants were cut suggests this advantage of stimulus to early growth. If this is the true explanation, it indicates that the phosphates do not move to the roots so much as the roots move to the phosphates.

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EFFECT OF INCREASING QUANTITIES OF SOIL ON THE EFFICIENCY OF SUPERPHOSPHATE

Data given in tables 17 to 22, inclusive, snow now the efficiency of a fixed quantity of superphosphate varies as increasing quantities of soil are mixed with the quartz sand. The results are shown graphically in figure 1.

The curves for different soils all show the same general form; the efficiency falls rapidly with the first additions of soil and is not much affected by further increments. The two curves for Nipe soil, no. 1, plotted for the series receiving 0.05 g of P_2O_5 per pot, and no. 3 for the series receiving 0.135 g of P_2O_5 show that the falling off in efficiency with increasing quantities of soil is less sharp, the more superphosphate is applied.

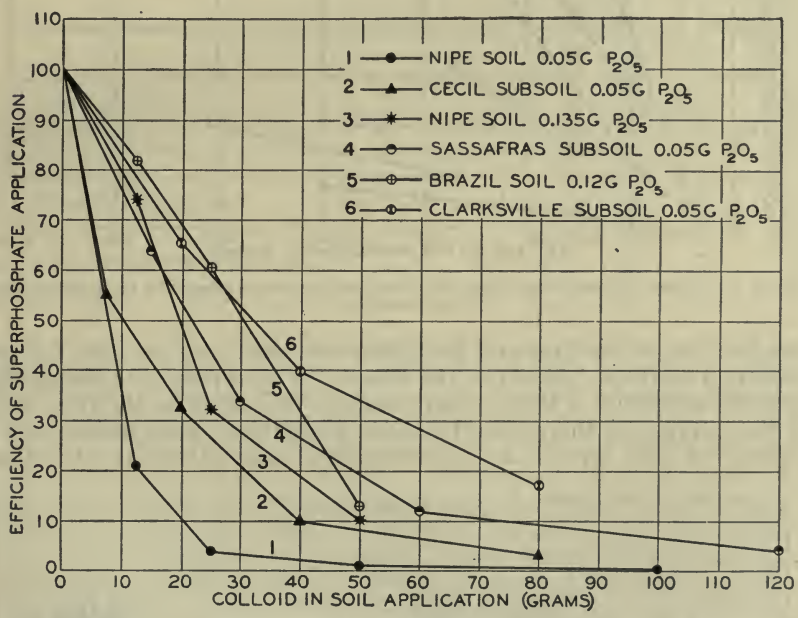

FIGURE 1.—Efficiency of a superphosphate application as affected by the quantity of soil mixed with quartz sand.

It is apparent from a comparison of these curves that comparative figures for the effects of different soils on phosphate efficiency may vary considerably, according to whether the comparison is based on the effect of 25 or 50 g of soil colloid.

EFFICIENCIES OF INCREASING SUPERPHOSPHATE APPLICATIONS WITH A FIXED QUANTITY OF SOIL

Before the effects of different soil colloids on superphosphate could be compared, it was necessary to determine how the effect varied with the quantity of superphosphate applied. Measurements of the effect of a fixed quantity of soil on the efficiencies of different quantities of superphosphate are found in tables 15, 17, 18, 21, and 22. The results of the different experiments are shown in figure 2, and a representative experiment is illustrated in figure 3.

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Evidently in all cases the efficiency of the superphosphate, as expressed, is practically a straight-line function of the quantity of phosphate applied. Within the limits of experimental error, all curves would, on projection, pass through the origin. Actually,

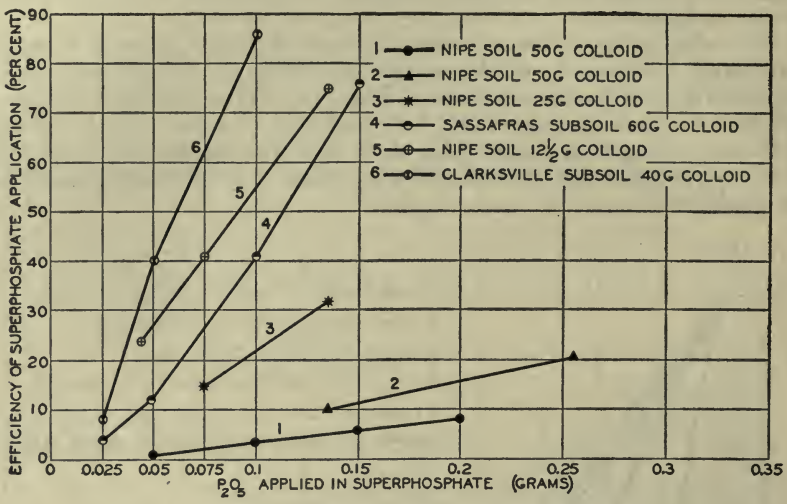

FIGURE 2.—Efficiency of superphosphate in mixtures of soil and sand as affected by the quantity of phosphate applied.

however, when the first and last points on the curve are used for projection, 4 of the 6 curves cut the abscissa within points corresponding to 0.018 and 0.021 g P_2O_5. Some such point might be the true origin of the curves, as there may be some quantity of phosphates held so tightly by the soil as to be completely unavailable to the plant.

FIGURE 3.—Effect of increasing supersphosphate in sand and in a sand-Sassafras-subsoil mixture as shown by the growth of millet (table 21). 1, Sand only, no P_2O_5; 2, sand only, 0.025 g P_2O_5; 3, sand only, 0.05 g P_2O_5; 4, sand only, 0.1 g P_2O_5; 5, sand and soil, 0.025 g P_2O_5; 6, sand and soil, 0.05 g P_2O_5; 7, sand and soil, 0.1 g P_2O_5; 8, sand and soil, 0.15 g P_2O_5.

However, except for this small unexplored region lying near the limits of experimental accuracy, it is evident from the curves that there is no definite saturation point of the soil which must be exceeded before any phosphoric acid at all is available. It seems, on the other hand, that the absolute quantity of phosphate rendered unavailable by the

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soil increases with increasing application up to a certain point (table 4), although the percentage rendered unavailable decreases.

TABLE 4.—*Summary of results showing how the efficiency of superphosphate in a soil-and-sand mixture varies with the quantity of superphosphate applied*

Table no. from which data were obtained	Kind of soil mixed with quartz sand, and quantity in terms of colloid content	P_2O_5 applied per pot	Efficiency of the P_2O_5	Quantity P_2O_5 rendered ineffective by the addition of soil to quartz sand
		Grams	*Percent*	*Grams*
18	Nipe soil, 50 g	0.05	1	0.0495
		.10	3.5	.0965
		.15	6	.1410
		.20	8	.1840
17	do	.135	10	.1215
		.255	21	.2015
17	Nipe soil, 25 g	.075	15	.0638
		.135	32	.0918
17	Nipe soil, 12½ g	.045	24	.0342
		.075	41	.0443
		.135	75	.0338
21	Sassafras subsoil, 60 g	.025	4	.0240
		.050	12	.0440
		.100	41	.0590
		.150	77	.0345
22	Clarksville subsoil, 40 g	.025	8	.0230
		.050	40	.0300
		.100	86	.0140

The slopes of curves for the Clarksville and Sassafras subsoils and for Nipe soil applied at the rate of 12½ g of colloid suggest that these particular applications might render some quantity of superphosphate more efficient than superphosphate in pure quartz sand, in spite of the fact that these soil additions markedly depressed the efficiency of small quantities of superphosphate. This, however, is projecting the results into the region of maximum growth where this method of study, or the particular technic employed, breaks down. As pointed out under Plan and Methods, the method of testing efficiencies adopted is valid only so long as the comparison between the pure quartz sand and the soil-sand cultures is made with a quantity of superphosphate that is in minimum. When a quantity of superphosphate near the optimum is used, secondary effects of the soil which are beneficial to growth begin to affect the yield, and with still more phosphate the yield should become higher in the soil-sand mixture than in pure sand, as actually occurred in some cases (tables 17, 21, 25).

In table 4 the quantities of P_2O_5 rendered unavailable, or ineffective, as compared with superphosphate in pure sand, are given. This shows better than the graphs how markedly the "fixed", or ineffective, P_2O_5 increases as increasing quantities of superphosphate are applied. Another point not brought out in the graphs is that the Clarksville and Sassafras subsoils and Nipe soil, at the rate of 12½ g of colloid, seemingly render ineffective less P_2O_5 from the heaviest superphosphate application than from smaller applications. In these three cases the quantity of superphosphate applied was sufficient to bring the growth into the region of maximum growth where the method of studying efficiencies is inapplicable, since there, the soil-sand cultures are at an advantage over the pure sand cultures.

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The marked increase in efficiency of large over small applications of superphosphate in the presence of soil evidently holds for most of the soils. Data are given in tables 16 and 23 for the efficiency of 0.12 g P_2O_5 in the presence of different soil applications providing 50 g of colloid. The figures obtained for efficiency in these experiments may be compared with those obtained in other experiments where the superphosphate application was 0.05 g P_2O_5 per pot. Mentioning the efficiency of the 0.12 g P_2O_5 application first and that of the 0.05 g P_2O_5 second, the results are as follows: Cecil soil, 70 against 28; Norfolk soil, 24 against 6; Sassafras soil, 111 against 75; Hagerstown subsoil, 40 against 4; and Orangeburg subsoil, 33 against 1.

Inasmuch as curves for the efficiency of increasing applications of superphosphate all approximate straight lines passing through the origin, it is evident that the effects of different soils on efficiency can be fairly compared on the basis of any one fixed quantity of superphosphate. The quantity used for the comparison described later was 0.05 g of P_2O_5 per pot, this being a dose below the optimum for pure quartz sand and one that gives measurable increases in growth with markedly depressing soils.

The facts brought out in this particular section of the study may have a further bearing on the comparative effects of different soils on superphosphate. The fact that the percentage of the superphosphate application rendered unavailable decreases with increasing size of the application suggests that the effects of different soils on a given phosphate application may depend largely on how nearly saturated the soils are with P_2O_5. The soils that are more nearly saturated with P_2O_5 would evidently render unavailable a smaller proportion of any superphosphate application than the less saturated soils; in other words, they would depress efficiency less.

EFFECTS OF COLLOIDAL AND NONCOLLOIDAL SOIL FRACTIONS ON SUPERPHOSPHATE

Although it seems evident from previous work on the properties of colloidal and noncolloidal soil fractions (*3*) that the reaction of noncalcareous soils with superphosphate must be confined almost exclusively to the colloidal material, an attempt was made to show this directly. The plan was to separate the soil into colloidal and noncolloidal fractions and compare the effects of these fractions on superphosphate efficiency with the effect of the unfractionated soil material.

Certain difficulties in this simple procedure were apparent at the outset. A complete separation of colloidal material is practically impossible; hence the noncolloidal fraction is bound to contain more or less colloid. However, the quantity of colloid remaining in the noncolloidal fraction can be estimated fairly well by the water-adsorption method (*43*), and allowance can be made for this in interpreting the results. A more serious difficulty anticipated was that the effect of the colloid on superphosphate might be altered by the process of extraction, since early work showed that the adsorptive capacities of some colloids for dye, water, and ammonia were materially altered by the extraction process (*22*). Alteration was especially feared in this work, inasmuch as the soils suitable for this experiment, those markedly depressing the efficiency of superphosphate, contain colloid that is difficult to extract, and ammonia must be used to obtain fairly clean separation. A third difficulty

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anticipated was that the fractions might accumulate sufficient heavy metals in the process of separation to render them injurious to plants. The agitator used for dispersing the soil and the supercentrifuge used for separating the colloid expose copper, brass, tin, and iron to the soil and water under somewhat abrasive conditions.

The Cecil, Sassafras, and Clarksville subsoils, which markedly depressed superphosphate efficiency, were fractionated for this experiment by a procedure previously described (*27*). Approximately 90 percent of the colloid present in each soil was extracted by repeated use of the dispersion apparatus and addition of distilled water brought to a pH of 8 or 9 with ammonia. Tests of the noncolloidal fractions for adsorption of water vapor indicated that they contained 6 to 8 percent of unextracted colloidal material. The extracted colloidal material was dried on the steam bath and ground to pass a ½-millimeter sieve before being mixed with the sand.

The three soils were not fractionated at the same time. Fractions of the Cecil subsoil were first prepared and these were at once used

FIGURE 4.—Effects of colloidal and noncolloidal fractions on superphosphate as shown by the growth of millet (table 20). 1, Sand only, 0.05 g P_2O_5; 2, sand plus 20 g of colloidal fraction, 0.05 g P_2O_5; 3, sand plus 40 g of noncolloidal fraction, 0.05 g P_2O_5; 4, sand plus soil at rate of 80 g of colloid, 0.05 g P_2O_5; 5, sand plus soil at rate of 40 g of colloid, 0.05 g P_2O_5; 6, sand plus soil at rate of 20 g of colloid, 0.05 g P_2O_5; 7, sand plus soil at rate of 10 g of colloid, 0.05 g P_2O_5.

in the pot experiment shown in table 19. A year later fractions of the Sassafras subsoil and Clarksville subsoil were prepared and used shortly thereafter in experiments shown in tables 21 and 22. Fortunately, at this time it was decided, for no particular reason, to repeat also the experiment with the Cecil subsoil fractions, utilizing what remained of the material prepared in the previous year. The results of this experiment are shown in table 20 and illustrated in figure 4. There were thus three experiments with freshly prepared fractions and one with fractions 1 year old.

Tables 19, 21, and 22, giving data for the fractions applied shortly after preparation, show that the extracted colloids depress the efficiency of superphosphate much more than an application of the whole soil containing the same amount of colloid; the noncolloidal fractions depress superphosphate slightly or markedly less than a similar quantity of extracted colloid; and the combined fractions depress the superphosphate much more than equivalent quantities of the untreated soils. The experiment with the Cecil subsoil

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fractions repeated a year after the fractions had been prepared gave somewhat different results (table 20). The extracted colloid gave the same efficiency of superphosphate as the soil application furnishing a like quantity of unextracted colloid. The noncolloidal residue applied at double the rate of the extracted colloid depressed growth much less than the colloidal fraction.

Only this qualitative idea of the effects of the fractions is afforded by the figures given in tables 19 to 22, since, as already shown in figure 1, the depression in phosphate efficiency is not in direct proportion to the quantity of soil applied, but falls off at a diminishing rate as the soil is increased. A quantitative measure of the effect of a fraction, however, is given by the quantity of soil required to produce the same result (that is, the same lowering in efficiency) as the fraction. The results obtained in the four experiments are shown in this quantitative manner in table 5. The quantities of soil required to produce the same results as the fractions were obtained from the curves given in figure 1.

TABLE 5.—*Summary of results showing the effects of colloidal and noncolloidal soil fractions on the efficiency of superphosphate in quartz sand*[1]

Soil type	Extracted colloid, applied per pot	Colloid in quantity of untreated soil, producing same effect	Noncolloidal residue, applied per pot	Colloid in quantity of untreated soil, producing same effect	Extracted colloid and noncolloidal residue, combined in proportions present in soil, applied per pot	Whole untreated soil, producing same effect
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Cecil subsoil	40	90	47	72	44	112
Cecil subsoil, fractions 1 year old	20	20	40	15	----------	----------
Sassafras subsoil	40	80	40 120	21 26	60	153
Clarksville subsoil	40	110	40 120	35 64	80	377

[1] Calculations based on data given in tables 19 to 22.

If, for convenience in discussing the results of table 5, it is assumed that only the colloid in the untreated soil affects the phosphate, then it appears that the year-old extracted colloid of Cecil subsoil is equal in effectiveness to the unextracted colloid, but the three other freshly prepared, extracted colloids are 2 to nearly 3 times as effective as the soil colloid. It seems obvious, then, that the reactivity of the colloidal material in the soil is increased by the process of extraction, and that this increased reactivity is lost as the fraction ages.

The figures in the fourth and fifth columns showing the effects of noncolloidal fractions might be fairly well explained on similar grounds, that the extraction process had increased the reactivity of the unextracted colloid in these fractions and this activity was largely, but not completely, lost in the case of Cecil subsoil by aging for 1 year. Figures for the recombined soil fractions in the last two columns of the table give direct proof that the process of separating the fractions has markedly increased the effect of the material on plant growth, whatever the explanation. The increased effect of freshly prepared

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colloid may be due to increased hydration of ferric oxide with consequent greater facility for combination with phosphoric acid, or it may be that the freshly prepared colloid after being dried on the water bath is more permeable to the solution and consequently reacts more readily with the phosphoric acid. The loss of activity on aging might be due to dehydration, or the permeability may be lessened on aging.

From comparison of fresh and aged Cecil colloids it seems that increased reactivity of the colloid is the chief reason for recombined soil fractions having a much greater effect than untreated soil; but observation of the plants during growth indicates that another factor may play a part in this enhanced effectiveness of the recombined soil fractions.

In all four experiments it was noted that plants growing in pots receiving the noncolloidal fraction differed somewhat in appearance from plants receiving untreated soil or extracted colloid. In the pots with the noncolloidal fractions the stand of plants was very irregular; the larger plants were as dark green as any plants in the experiment but were affected with a slight striation in the leaves that was usually most pronounced in the next to last leaf; root development was also inferior to that of plants making similar growth in the presence of untreated soil, the roots being short and stubby, similar to those developed in an unfavorable medium. On the other hand, plants growing in pots receiving the extracted colloid had the same appearance as those making equivalent growth in the presence of the untreated soil. There is thus some indication in the appearance of the plants that the noncolloidal residues and the recombined fractions may owe part of their effect to another factor. This factor may be a contamination of the fraction with heavy metals picked up in the process of fractionation. The fact that the effect of the noncolloidal fraction measured in terms of the whole soil was not trebled when the quantity applied was trebled is in accord with this supposition.

Several months after the characteristics mentioned above of plants grown with the extracted noncolloidal fractions were noted, it was found that Forbes (*14*), several years ago, described as symptoms of copper injury in corn plants some of the same characteristics: viz, a yellow striation of the leaves and a restricted development of roots, crinkled in form.

The results of these experiments support the idea that the colloidal material is the only part of the soil affecting the efficiency of superphosphate, since the colloidal fractions show a much greater effect than the noncolloidal fractions. But the demonstration is far from clear-cut, because both fractions exert more than their required effects. These discrepancies seem to be satisfactorily explained by changes, including contamination, brought about in the process of separation; hence it is assumed in the discussion that follows that the soil colloids are the material affecting the superphosphate.

Further evidence that reaction of the soil with superphosphate is chiefly concerned with the colloidal material lies in the high percentages of phosphoric acid found in soil colloids by several investigators (*10, 19, 44*), since it is probable that the high percentages are chiefly due to adsorption. This is supported by Ford's (*15*) data showing that the use of superphosphate on the experiment plots of

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the Kentucky Agricultural Experiment Station has enriched with phosphoric acid chiefly the clay fraction. Brown and Byers' (*10*) data showing that the highest content of phosphoric acid usually occurs in the 1 to 5 micron fraction, suggest that adsorption of phosphoric acid may lead to some aggregation of the soil colloids.

EFFECTS OF DIFFERENT SOIL COLLOIDS ON SUPERPHOSPHATE EFFICIENCY

The conditions adopted for determining the effects of different soil colloids on superphosphate were as follows: The different soils were added to the quartz sand in amounts which would furnish 50 g of colloidal material in each case; the superphosphate application furnished 0.05 g of P_2O_5 per pot; and base fertilizer no. 2 of table 1, with part ammonia and part nitrate nitrogen, was used. Somewhat different values would probably have been obtained with different quantities of soil and phosphate, with a test plant that was a "stronger feeder" on phosphate than millet, with a base fertilizer physiologically alkaline rather than acid, or with superphosphate applied some time prior to planting. The particular values obtained for the efficiency of superphosphate are therefore of general significance only in a comparative sense.

Data for the effects of the different soils under these experimental conditions are found in 10 experiments reported in tables 18, 20, 21, 24, 25, 26, 27, 28, 29, and 31. These experiments were conducted at different times under varying conditions of light, temperature, and humidity. The results of these experiments are brought together in table 6.

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TABLE 6.—*Correspondence between silica-sesquioxide ratio of the soil colloid and effect of the soil on the efficiency of superphosphate in quartz sand* [1]

Soil type (surface soils)	pH concentration of medium after growth	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratio of colloid	Average efficiency of superphosphate in soil-sand mixture [2]	Duplicate determinations of efficiency
			Percent	
Sharkey	4.8	3.23	148	
Wabash	4.7	3.16	198	
Stockton	6.7	2.87	146	
Marshall	5.0	2.82	142	
Carrington	4.8	2.75	54	50, 58
Miami	4.8, 5.2	2.50	62	73, 48
Clarksville	4.6 to 5.3	2.18	71	73, 77, 64, 68
Hagerstown	6.7, 6.9	1.91	11	11, 10
Huntington	4.6	1.86	72	
Sassafras	4.7, 4.4	1.85	75	51, 98
Orangeburg	4.4	1.83	66	
Chester	5.6	1.77	38	
Manor	4.7, 4.9	1.74	50	60, 40
Norfolk	5.2	1.67	6	
Cecil	4.9 to 5.2	1.34	28	14, 32, 37
Brazil [3]		.85	<13	
Nipe	6.5	.41	1	
Coefficient of correlation between silica-sesquioxide ratio and efficiency		+0.84		

Soil type (subsoils)	pH concentration of medium after growth	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratio of colloid	Average efficiency of superphosphate in soil-sand mixture [2]	Duplicate determinations of efficiency
			Percent	
Wabash	4.6	3.33	175	
Marshall	5.6	2.87	52	
Stockton	8.1	2.85	130	
Miami	7.8, 7.9	2.66	28	38, 18
Carrington	5.0	2.64	78	
Clarksville	4.8 to 5.4	2.10	13	10, 19, 10, 14
Sassafras	6.3	1.89	18	16, 19
Huntington	6.2	1.89	4	
Hagerstown	6.6, 6.8	1.89	8	10, 6
Norfolk	4.6	1.84	1	
Manor	5.3	1.81	20	
Chester	4.7	1.79	2	
Orangeburg	4.8	1.71	1	
Cecil	4.5 to 5.7	1.20	17	23, 24, 16, 11, 9
		+0.83		

[1] Soils applied at rate of 50 g of colloid per pot, superphosphate at rate of 0.05 g of P_2O_5.
[2] As compared with 100, for efficiency in sand alone.
[3] Superphosphate applied at rate of 0.12 g of P_2O_5 instead of 0.05 g. Judging by the results with other soils, notably the Nipe, the efficiency with 0.05 g of P_2O_5 would have been 1 or 2. The value 2 is used in calculating the correlation coefficient.

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The accuracy of the average figures given for the efficiency of superphosphate in columns 4 and 9, or the range within which these figures are significant, can be judged somewhat from variations in the duplicate determinations shown in columns 5 and 10. Differences between duplicates are probably chiefly due to the usual experimental errors attending pot experiments and probably in part to variable growth conditions in different experiments and to slight differences in the various lots of quartz sand.

The variation in the effects of different soils on superphosphate is very remarkable. In the presence of Nipe soil, superphosphate is only one hundredth part as efficient as in pure quartz sand, whereas in the presence of Wabash soil it is almost twice as efficient as in sand. A similar wide variation obtains in the effects of subsoils. The figures for efficiencies above 100 percent are not anomalous, for it was found by analyzing the crops that in the quartz sand cultures the recovery of P_2O_5 in the part of the plant aboveground was only 30 to 40 percent of that applied.

The figures given for hydrogen-ion concentration show that this wide variation in the effects of different soils is not primarily concerned with the reaction, although, as will be shown later, the hydrogen-ion concentration affects the results somewhat.

Another fact standing out clearly is the difference in the effects of soil and subsoil materials. In every case except the Carrington, the subsoil imparts a lower efficiency to superphosphate than the corresponding topsoil. In the case of the Wabash and Stockton soils and subsoils the differences are hardly significant, but in all other cases they are obviously real, and in the case of the Marshall, Clarksville, Huntington, Sassafras, Orangeburg, and Chester soils the depressing effect of the subsoil is enormous, as compared with that of the soil.

When the surface soil and subsoil materials are taken as forming a single series there is practically no correspondence between silica-sesquioxide ratios of the colloids and effects of the materials on superphosphate. If, however, soil and subsoil materials are considered in separate groups, a fairly good correspondence obtains between silica-sequioxide ratios and efficiency figures in the case of both soil and subsoil colloids, the correlation coefficients being, respectively, +0.84 and +0.83. These coefficients indicate somewhat less than the actual correspondence, since the efficiency is apparently not a straight-line function of the ratio. It seems, then, that the silica-sesquioxide ratio is one of the factors concerned with, or associated with, the action of the material on superphosphate. But it is obviously not the chief factor; because soil and subsoil materials give very different results, although they have practically the same ratios in nearly all cases.

The fact that differences between the effects of soil and subsoil materials are so marked and so general points to some difference generally obtaining between soil and subsoil colloids as one of the chief factors determining the effects of the colloids. Complete ultimate analyses of the colloids previously made by Robinson and Holmes (*44*) show that in the case of these soils the colloids from the topsoil and subsoil strata are very much alike in composition. The only consistent differences are in the minor constituents—manganese, organic matter, nitrogen, and the anions, P_2O_5, Cl_2, SO_4. These constituents are nearly always higher in the surface soil colloids. An increase in manganese would be expected to depress rather than

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enhance phosphate efficiency, but organic matter in some instances has been found to increase the efficiency of insoluble phosphates; and an increased percentage of P_2O_5 might also be considered favorable as indicating a reduced affinity of the colloid for phosphate, owing to the colloid being more nearly saturated with phosphorus.

Table 7 gives the percentages of P_2O_5 and organic matter in the colloids, previously published (*44*), for comparison with the effects of the soils on phosphate efficiency.

TABLE 7.—*Relation between comparative effects of topsoil and subsoil on superphosphate efficiency and other data for topsoil and subsoil*

Soil type	Efficiency of superphosphate	P_2O_5 in colloidal material	Yield in soil-sand mixture minus yield in pure sand without superphosphate	Organic matter in colloidal material
	Percent	*Percent*	*Grams*	*Percent*
Wabash soil	198	0.25	+0.31	5.6
Wabash subsoil	175	.24	+.11	5.6
Stockton soil	146	.06	+.49	1.2
Stockton subsoil	130	.20	+1.24	2.8
Marshall soil	142	.46	+1.58	8.6
Marshall subsoil	52	.21	0	4.0
Sassafras soil	75	.47	+.11	6.3
Sassafras subsoil	18	.08	+.03	1.6
Huntington soil	72	.64	+.53	9.8
Huntington subsoil	4	.35	-.13	6.1
Clarksville soil	71	.65	+.05	5.7
Clarksville subsoil	13	.38	-.05	2.3
Orangeburg soil	66	.42	+.23	4.3
Orangeburg subsoil	1	.17	-.01	1.6
Miami soil	61	.11	+.02	3.7
Miami subsoil	28	.21	-.01	.9
Carrington soil	54	.28	+.04	11.6
Carrington subsoil	78	.14	-.11	4.5
Manor soil	50	.28	-.05	3.7
Manor subsoil	20	.46	-.23	2.6
Chester soil	38	.20	+.17	4.1
Chester subsoil	2	.15	-.09	5.0
Cecil soil	28	.25	+.03	2.3
Cecil subsoil	15	.11	0	1.4
Hagerstown soil	11	.30	-.05	7.0
Hagerstown subsoil	8	.20	-.07	2.7
Norfolk soil	6	.23	-.13	4.7
Norfolk subsoil	1	.26	-.26	2.7

There is practically no correspondence between the efficiency figures of different soils or subsoils and the percentages of organic matter or phosphorus present, but in all cases except two a higher percentage of organic matter in the topsoil colloid than in the subsoil colloid correlates with higher superphosphate efficiency. The figures for percentages of P_2O_5 are not so significant. In 5 cases out of 14 a higher percentage of P_2O_5 in the topsoil or subsoil colloid is not in qualitative agreement with the comparative efficiency figures of topsoil and subsoil.

It was thought that a better indication of the comparative phosphorus saturations of topsoil and subsoil colloids might be afforded by the proportion between PO_4 and the sum of the anion equivalents, PO_4, Cl, and SO_4. But, strangely enough, this proportion seemed to be practically a constant for the soil and subsoil colloids analyzed by Robinson and Holmes (*44*). Data given for 24 samples show that the PO_4 anion averaged 63.6 percent of the total anion equivalents,

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and the standard deviation of single samples from the average was only ± 9.5. This, incidentally, seems to be analagous to the fairly constant proportion of calcium in the exchangeable bases, to which attention has been called by Anderson and Mattson (*4*).

Another figure indicative of phosphorus saturation of the colloid may be obtained from certain data of the pot experiments. The increases in growth produced by the simple addition of soil to quartz sand without a superphosphate application ought to be significant, since this treatment constitutes a sort of Neubauer test for the availability of soil phosphorus, and phosphorus saturation ought to be related in some measure to availability. At least, one would hardly expect a soil to be high in available phosphorus if the colloidal material were markedly unsaturated with phosphoric acid and vice versa. Increases in growth produced by the addition of different soils to quartz sand without a superphosphate application are shown in column 4 of table 7.

These figures, representative of the availability of the soil phosphorus, agree with the efficiency data so far as the comparative effects of soil and subsoil are concerned, for all soils except the Stockton and Carrington. Possibly special conditions were operative in the case of these two soils, since they were exceptions also to the agreement of efficiency data with percentages of P_2O_5 and organic matter. The availability figures also show a low correlation with the efficiency figures of different soils and subsoils. In this respect the availability data are more significant than either the percentage of total P_2O_5 or the percentage of organic matter.

It should be pointed out, however, that the figures tabulated as indicative of available phosphorus are only approximate and not strictly comparable for all soils, owing to the fact that the pure-sand cultures evidently contained small but variable amounts of phosphate impurities in the different experiments. This is shown by the yields of the pure-sand-no-phosphate pots, varying in different experiments from 0.06 g to 0.36 g of dry matter. Most of the availability data were taken from experiments where the yields of these check pots were from 0.06 to 0.15 g, and are therefore nearly comparable. But figures for the Huntington, Carrington, Manor, and Norfolk soils were available only in experiments where there were obviously more phosphate impurities, the check pots yielding 0.31 and 0.36 g, respectively. Under these conditions no significance should be attached to varying negative values. So far as availability of soil phosphorus is concerned, all negative values mean simply zero availability. The comparative magnitudes of the negative values are due to varying amounts of phosphorus impurities in different experiments and to the effects of the soils in rendering these impurities unavailable. The different negative values, therefore, constitute simply a further test of the soil's influence on phosphate efficiency conducted with small amounts of phosphate impurities. The different positive values, on the other hand, are to be regarded as indicating different quantities of available phosphorus in the soils.

The data presented thus far indicate that the wide differences of soil material on superphosphate efficiency are dependent in some degree on the silica-sesquioxide ratio of the colloidal material. There is also some evidence that variations in the effects of those colloids that depress superphosphate efficiency may be largely dependent on the

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extent to which these colloids are saturated with phosphorus. This is suggested by the increased efficiency of increasing superphosphate applications, pointed out in a previous section, by the comparative percentages of total phosphorus in soils and subsoils, and by data indicating the availability of the phosphorus present in the soil. Evidence as to other factors governing the effects of different soils on superphosphate was obtained in further experiments.

Laboratory studies of other investigators substantiate some of the facts and conclusions discussed in this section.

That surface soils contain more available phosphoric acid than subsoils is supported by data reported by Engels (*12*), Kling and Engels (*30*), and Hasenbäumer and Balks (*24*). According to these investigators, surface soils contain more phosphoric acid soluble in citric acid and more phosphoric acid available by the Neubauer method than subsoils. Also, according to Honcamp and Steinfatt (*28*), the quantity of phosphoric acid soluble in 10 percent hydrochloric acid is greater in surface soils than subsoils, and the part of the acid-soluble phosphoric acid which is available by the Neubauer method is greater in surface soils. Also, recent data of McGeorge (*34*) indicate that phosphoric acid removable by electrodialysis is likewise higher in surface soils than in subsoils.

That a high availability of the soil phosphorus is associated with high saturation of the soil with phosphoric acid, or at least, with low ability of the soil to adsorb more phosphoric acid, is indicated by another recent investigation. Rauterberg (*42*) shows that in the case of 19 soils, a fairly close inverse relation obtains between the phosphoric acid available by Neubauer's method and the phosphate adsorbed from a phosphate solution. In the case of three soils high in available phosphorus, there was a release of phosphate ions to the phosphate solution instead of adsorption.

Scarseth (*45*), in a recent study of Alabama soils, found that soils containing colloids of low silica-sesquioxide ratios had a marked tendency to fix more phosphate than soils containing colloids of high ratios. The criterion of fixation was solubility of the P_2O_5 in a water extract.

THE HYDROGEN-ION CONCENTRATION AS A FACTOR INFLUENCING THE EFFECT OF SOIL ON SUPERPHOSPHATE EFFICIENCY

Columns 2 and 7 of table 6 show that the different soil-sand mixtures had very different hydrogen-ion concentrations in many cases. Although it is obvious from the table that the effects of different soils were not primarily dependent on the hydrogen-ion concentration, it was presumed that this had some influence on the results, since an effect of liming on superphosphate efficiency was observed in a previous study (*21*).

In nearly all experiments approximate determinations were made of the hydrogen-ion concentration of the soil and sand mixtures after the plants had been harvested. The colorimetric method was used, and the proportion of soil to water was about 1 to 2. The determinations were accurate to only about two tenths of a pH.

As data accumulated, it became evident that the following conditions affected the hydrogen-ion concentration: The growth of the plants, the composition of the base fertilizer, and the nature of the soil addition. When the standard base fertilizer supplying one half

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nitrate and one half ammonia nitrogen was used in pure quartz sand the pH of the medium was about 6.5 before planting and about 4.5 after the growth of the plants. (See tables 13, 18, 19, etc.) When an all-nitrate base fertilizer was used the plants rendered the sand more alkaline, about pH 7.3 (tables 14 and 18). The soil tended to modify the hydrogen-ion concentration developed in pure sand to that of the soil, the effect of the soil varying with its buffer capacity and the growth made by the plants.

Two experiments (tables 28 and 29)were conducted to determine whether the effect of the soil on superphosphate efficiency varies appreciably at different hydrogen-ion concentrations. In these experiments the hydrogen-ion concentrations of the soil-sand mixtures were varied by the application of sodium bicarbonate and by the use of two different base fertilizers, the standard (no. 2 of table 1) producing an acid reaction and the all-nitrate fertilizer (no. 7 of table 1) producing an alkaline reaction. The results of the two experiments are brought together in table 8.

TABLE 8.—*Summary of results which show the effect of the hydrogen-ion concentration on the efficiency of superphosphate in a mixture of soil and quartz sand* [1]

Kind of soil mixed with quartz sand	pH of medium after growth	Efficiency of superphosphate shown in—	
		Experiment 16	Experiment 18
		Percent	*Percent*
Cecil soil	5.0	32	----------
	5.2	----------	37
	6.2	----------	33
	6.3	33	----------
	6.6	----------	16
	7.1	----------	22
Cecil subsoil	4.5	24	----------
	5.7	----------	11
	7.2	----------	4
	7.8	----------	2
	8.2	13	----------
Clarksville soil	4.6	----------	68
	5.3	77	----------
	6.3	27	----------
	6.6	----------	44
	7.7	----------	38
Clarksville subsoil	4.8	19	----------
	5.4	----------	14
	6.8	----------	2
	6.8	----------	7
	6.9	8	----------
Sassafras soil	4.4	----------	98
	4.7	51	----------
	5.6	----------	35
	6.3	22	----------
	6.9	----------	52

[1] In all cases 0.05 g of P_2O_5 was applied per pot and soil added at rate of 50 g of colloid per pot. Base fertilizer varied to produce different reactions.

It should be borne in mind that the hydrogen-ion determinations in table 8, as in all others, show the hydrogen-ion conentration of the medium that was finally developed by the growth of the plants. At the beginning of the experiments the acid mediums were less acid than at the end; the pots receiving only the all-nitrate fertilizer were less alkaline at the beginning than at the end of the experiment, and pots receiving sodium bicarbonate were more alkaline at the beginning than at the end of the experiment.

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It is obvious from the results as a whole that the hydrogen-ion concentration has a marked influence on the extent that soil depresses the availability of superphosphate. The limits of maximum and minimum availability of the superphosphate cannot be defined closely because sufficient results were not obtained and the hydrogen-ion concentration varied more or less during the period of growth; but it seems certain that the maximum availability of superphosphate in the presence of these soils is in the acid range, somewhere about pH 4.5 to 5.0. The minimum availability seems to be somewhere around neutrality, pH 6.5 to 7.5, and there is a suggestion of a small increase in availability in the distinctly alkaline range.

These results are in accord with results obtained by Teakle (*47*) and by Gaarder (*16*) in studies of the solubility of phosphate ions in the presence of various cations. Gaarder found that the solubility of PO_4 ions in the presence of a mixture of Ca, Mg, Fe, Al, and Mn ions in excess was at a maximum at a pH near 4.5 and at a minimum around 5 to 6.5, and that the solubility increased again slightly between 6.5 and 8.0. He further found that some of the relations between cations and PO_4 solubility were greatly changed by the addition of silica.

Other soils may show a more constant effect on superphosphate at different hydrogen-ion concentrations than the Cecil, Clarksville, and Sassafras soils. If the analogy between these results and those of Gaarder holds further, the high silica colloids would be less affected by differences in acidity or alkalinity than the soils tested. But the results obtained are sufficient to show that the hydrogen-ion concentration is one of the factors determining the action of soil on superphosphate. If all the soils and subsoils could have been tested at the same hydrogen-ion concentration, it is possible that the efficiency figures would have shown a somewhat better correspondence with the silica-sesquioxide ratios. It seems probable that the two most marked exceptions to the parallelism between efficiency values and silica-sesquioxide ratios, the efficiency values for Hagerstown soil and Miami subsoil, may be due to the reactions of pH 6.7 and 7.8, respectively, obtaining in the soil-sand mixtures (table 6).

EFFECTS OF CHARCOAL AND PEAT ON THE EFFICIENCY OF SUPERPHOSPHATE AND ROCK PHOSPHATE

The marked differences observed in most cases between the effects of soil and subsoil on superphosphate suggested experiments with some purely organic materials. Tests were made with peat and activated charcoal. Peat was selected as an organic material, presumably analagous to the more persistent part of the soil organic matter, and activated charcoal was used because of its high adsorptive power and its "insolubility." The characteristics of these samples are described under Soils and Materials.

The peats and samples of activated charcoal purified from acid would all tend to render the medium more acid. A sample of activated charcoal purified from alkali was therefore included, to give some indication as to whether the results obtained were due solely to changes in the hydrogen-ion concentrations.

Two experiments were conducted with these materials (tables 30 and 31). One of these is illustrated in figure 5. The yields of the no-phosphate pots show that the charcoals without superphosphates

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had practically no effect on growth; hence they contributed only traces of available phosphorus. The peats, however, contributed a measurable quantity of available phosphorus, something approximately equivalent to the superphosphate application of 0.025 g of P_2O_5 in the pure quartz sand series.

The significant results of the two experiments are more readily seen in table 9. It will be noted that all samples except the peat of pH 3.5 increased the efficiency of superphosphates in pure sand quite markedly. In the soil-sand mixtures equally marked increases were produced by one of the charcoal samples. These increases produced were of the same order as those produced by soil colloids with highest silica-sesquioxide ratios. Since only 10 g of the organic materials were applied in these experiments, as compared with 50 g of the soil colloids, it seems that these organic materials have much more effect on superphosphate than the best of the inorganic soil colloids.

These results with superphosphate cannot, on the whole, be ascribed to changes in the hydrogen-ion concentration of the medium brought about by the organic materials, for in three cases where the efficiency

FIGURE 5.—Effect of charcoal in pure sand and in sand-soil mixtures as shown by the growth of millet (table 31). 1, Sand only, 0.05 g P_2O_5; 2, sand plus charcoal, 0.05 g P_2O_5; 3, sand plus Clarksville topsoil, 0.05 g P_2O_5; 4, sand plus Clarksville topsoil and charcoal, 0.05 g P_2O_5; 5, sand plus Clarksville subsoil, 0.05 g P_2O_5; 6, sand plus Clarksville subsoil and charcoal, 0.05 g P_2O_5; 7, sand plus Cecil subsoil, 0.05 g P_2O_5; 8, sand plus Cecil subsoil and charcoal, 0.05 g P_2O_5.

was markedly increased the charcoals produced no measurable alteration in the hydrogen-ion concentration. It is probable, however, that the reaction influenced the results somewhat, although the reactions of the mediums with and without the charcoals and peats are all in, or close to, the general region where maximum availability of the phosphate would be expected. Probably the reduced efficiency of superphosphate in sand with peat of pH 3.5 is only apparent, the growth being reduced by too marked acidity.

The results obtained with rock phosphate are similar to those obtained with superphosphate, except that charcoal of pH 9.6 purified from alkali reduced the efficiency of rock phosphate below the efficiency in pure sand. The final pH of 6.3 in this case was in the range within which superphosphate would likewise be expected to show a reduced efficiency. Thus there is evidence that the reaction of the medium is highly important in determining the efficiency of rock phosphate. It is obvious, however, that the beneficial effects of the charcoals and peats on the availability of rock phosphates are not due solely to modifications in the hydrogen-ion concentration, since there were increased efficiencies of rock phosphate attending changes in the pH from 4.8 to 5.0, 5.4, and 4.2.

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If the two results which were presumably determined chiefly by the hydrogen-ion concentration are disregarded, it seems that the organic materials increased the efficiency of superphosphate somewhat more than the efficiency of rock phosphate. This is very different from the effects obtained with silica gel some years ago. In that experiment, the addition of silica gel to pure quartz sand more than doubled the efficiency of rock phosphate and raised the efficiency of superphosphate by only 19 percent. The efficiency of rock phosphate in pure sand in that experiment was practically identical with the efficiency obtained in this work (table 30), so the experiments are obviously comparable.

TABLE 9.—*Summary of results showing the effects of activated charcoal and peat on the efficiencies of superphosphate and rock phosphate in quartz sand, and in mixtures of quartz sand and soil* [1]

Kind of charcoal or peat	Medium to which charcoal or peat was added	pH after growth with superphosphate		Efficiency of superphosphate as compared with 100 for the efficiency in each medium without charcoal or peat	pH after growth with rock phosphate		Efficiency of rock phosphate as compared with 100 for the efficiency in sand alone
		In medium with charcoal or peat	In corresponding medium without charcoal or peat		In sand with charcoal or peat	In sand alone	
				Percent			*Percent*
Charcoal of pH 4.1	Sand alone	4.2	4.2	130			
Charcoal of pH 4.3	do	4.5	4.5	166	5.0	4.8	117
Charcoal of pH 9.6	do	5.3	4.5	132	6.3	4.8	42
Peat of pH 5.8	do	5.6	4.5	206	5.4	4.8	150
Charcoal of pH 4.1	Sand and Clarksville topsoil.	4.7	4.2	125			
Charcoal of pH 4.1	Sand and Clarksville subsoil.	4.8	5.3	220			
Charcoal of pH 4.1	Sand and Cecil subsoil.	4.5	4.6	188			
Peat of pH 3.5	Sand alone	4.2	4.5	68	4.2	4.8	150

[1] Figures are based on data given in tables 12 and 17.

Silica gel, the charcoals, and the peats are alike in having the capacity for an exchange adsorption of cations, but the charcoals, and possibly the peats, have the capacity for adsorbing anions also. It was shown in a previous publication (*23*) that addition of silica gel to a suspension of rock phosphate in water increases the amount of phosphate in solution, and Gaarder (*16*) has shown that silica gel increases the amount of PO_4 ions in solution in the presence of the precipitating ions Al, Ca, etc. Possibly part of the effect of the silica gel, charcoals, and peats on the efficiency of phosphates lies in the adsorptive capacity of these materials for cations, ions forming insoluble phosphates such as Fe, Al, Ca, being adsorbed, and hydrogen or sodium ions forming soluble phosphates being released. It will be recalled that, prior to being washed, the charcoals were treated with NaCl. So they obviously exchanged Na or H ions.

Although there is evidence that such adsorptive effects are concerned in the action of these materials on superphosphate and rock phosphate, it is believed that an examination of a water extract of the sand or soil-sand mixtures would indicate that the cation and soluble PO_4 relations had not been changed sufficiently by the organic

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materials and silica gel to account for the effects on efficiency. It was shown, for instance, in table 12, that an appreciable reduction of the Ca and Mg in the base fertilizer and a reduction of the Fe below the amount used in the standard fertilizer produces no changes in the efficiency of superphosphate in pure sand; and when all the salts of the base fertilizer are reduced by one half, the early growth is not affected (table 15).

Probably an essential feature of the action of these materials in promoting phosphate efficiency is a micellar effect of the silica and organic particles. In the zone of contact between the roots and the adsorptive particles the reactions mentioned are doubtless intensified, owing to their being localized. Wiegner (*54*), for example, has shown a marked increase of hydrogen ions in the immediate neighborhood of soil particles, presumably in the so-called "doubled layer" of micron dimensions. A grosser localization of reaction in the vicinity of plant roots has recently been noted by Thom and Humfeld (*48*) and it was observed in this work that even in the pure sand cultures the hydrogen-ion concentration was often notably greater in the part of the pot where the roots were most abundant. Granting a localization of the reactions, the results obtained in the examination of free solutions would probably give only a qualitative indication of what may take place to a much greater degree in restricted zones of root "feeding", or, more particularly, in the micellar areas of the colloid particles.

The results obtained with these insoluble organic materials indicate, so far as they go, that the organic content of a soil colloid may be an important factor in determining the effect of the colloid on superphosphate. It would seem that the presence of organic matter in the soil colloid would tend to render the colloid promotive rather than depressive of phosphate efficiency, but the characteristics of the organic constituent of a soil colloid can hardly be distinctive from that of the material as a whole. If, for instance, the soil colloid as a whole is unsaturated with bases, the organic matter present is probably likewise unsaturated. Doubtless the effect of organic materials free from inorganic colloids would likewise vary considerably, according to the degree that they were saturated with different ions such as Ca, H, PO_4.

AVAILABILITY OF ROCK PHOSPHATE

It was not planned to study the effect of soil colloids on the efficiency of rock phosphate, but in the early part of this work rock phosphate was applied to some of the pots in order to determine whether the availability of this material was affected as much as superphosphate. The sand used in this experiment contained some alkali, so the pH of the sand and soil-sand mixtures were about 7.5. In this experiment (table 16) the rock phosphate showed no availability whatsoever, either in the pure quartz sand or in the soil-sand mixtures. This is very different from the 24 percent efficiency developed in the pure quartz sand of the experiment just discussed (table 30) where the pH was 4.5.

These results, and the practical unavailability of rock phosphate in limed soils frequently observed (*21*, *41*), indicate that the availability of rock phosphate is governed primarily by the hydrogen-ion

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concentration. However, the results given in table 30 and the previous results with silica gel show that within the range of acid reaction other factors may promote or depress the efficiency of this material.

EFFICIENCIES CALCULATED FROM THE WEIGHT OF THE CROP AND FROM THE P_2O_5 RECOVERED IN THE CROP

In this work the efficiency of superphosphates was usually calculated from the weight of the crop, as described in detail under Plan and Methods; whereas, the recognized method is to base the calculation on the quantity of P_2O_5 in the crop. A theoretical justification for using simply the crop weight as a criterion of efficiency was given in a previous publication (*20*), but it seemed advisable to compare the two methods. Accordingly, a good many of the crops were analyzed for P_2O_5 by methods of the Association of Official Agricultural Chemists (*5*), the dry matter being ignited with magnesium nitrate and the phosphoric acid determined volumetrically.

The essential analytical results are shown in tables 24, 25, 30, and 31. The crops receiving no phosphate fertilizer were of course analyzed in estimating the P_2O_5 recovered, but these figures, of no particular significance, are not shown in the tables.

Usually when different phosphatic fertilizers are compared with a standard fertilizer the efficiencies are calculated simply from the ratio of the quantities of P_2O_5 recovered, modified by the ratio of quantities of P_2O_5 applied if these quantities are different for the standard and unknown fertilizer. When several different quantities of the standard phosphate have been applied it is theoretically more accurate to base the efficiency calculation on the comparative quantities of the two fertilizers required to give the same recovery of P_2O_5 (*20*). This method, described under Plan and Methods, was used in calculating the figures given in tables 24, 25, 30, and 31 for efficiencies based on P_2O_5 recovered. These two methods can also be followed when the data used are simply crop increases instead of P_2O_5 recovered.

Table 10 shows efficiencies calculated by the two methods, using both the weights of crop increases and of P_2O_5 recovered as criteria.

TABLE 10.—*Comparison of different methods of calculating efficiencies of phosphatc*

[Data from tables 17, 24, 25, 30, 31]

Conditions of experiment			Efficiency calculated from ratio of—		Efficiency calculated from comparative quantities of P_2O_5 required to give equal—	
P_2O_5 applied per pot (gram)	Kind of phosphate	Materials added to quartz sand	Weights of crop increases	Quantities of P_2O_5 recovered	Increases in weights of crops	Quantities of P_2O_5 recovered
			Percent	*Percent*	*Percent*	*Percent*
0.05	Super	Carrington soil	54	49	51	50
.05	do	Carrington subsoil	78	75	76	78
.05	do	Clarksville soil	66	68	64	73
.05	do	Clarksville subsoil	14	9	13	10
.05	do	Manor soil	61	58	58	60
.05	do	Manor subsoil	22	18	21	20
.05	do	Miami soil	66	70	63	73
.05	do	Miami subsoil	41	35	38	38
.05	do	Chester soil	36	44	30	38
.05	do	Sharkey soil	138	204	159	148
.05	do	Stockton soil	141	204	186	146

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TABLE 10.—*Comparison of different methods of calculating efficiencies of phosphate*—Continued

Conditions of experiment			Efficiency calculated from ratio of—		Efficiency calculated from comparative quantities of P_2O_5 required to give equal—	
P_2O_5 applied per pot (gram)	Kind of phosphate	Materials added to quartz sand	Weights of crop increases	Quantities of P_2O_5 recovered	Increases in weights of crops	Quantities of P_2O_5 recovered
			Percent	*Percent*	*Percent*	*Percent*
0.05	Super	Stockton subsoil	102	172	105	130
.20	Rock	Nothing	16	24	16	24
.05	Super	Charcoal of pH 4.3	149	182	200	166
.20	Rock	do	18	28	19	28
.05	Super	Charcoal of pH 9.6	125	141	153	132
.20	Rock	do	7	11	7	10
.05	Super	Peat of pH 5.8	152	231	215	206
.20	Rock	do	26	39	27	36
.05	Super	Peat of pH 3.5	50	72	52	68
.20	Rock	do	13	39	14	36
.05	Super	Charcoal of pH 4.1	163	140	----------	130
.05	do	Clarksville soil	50	46	64	64
.05	do	Clarksville soil and charcoal	101	71	100	80
.05	do	Clarksville subsoil	8	4	12	10
.05	do	Clarksville subsoil and charcoal	16	11	27	22
.05	do	Cecil subsoil	11	7	18	16
.05	do	Cecil subsoil and charcoal	25	15	42	30

If columns 6 and 7 are compared, it will be seen that it makes little difference whether the efficiencies are based on weights of crop increases or on quantities of P_2O_5 recovered when the method of calculation used in this study is followed. The only consistent differences between the two bases of calculation are in the efficiencies of rock phosphate, the efficiency calculated from the P_2O_5 recovered being uniformly higher than the efficiency calculated simply from the increases in yield. This is doubtless owing to the fact that with the physiologically acid fertilizer used in these experiments, the assimilation of P_2O_5 from rock phosphate is at an accelerated rate. As the plants grow and use up the nitrogen, the medium becomes increasingly acid and the rock phosphate becomes increasingly available.

Columns 4 and 5 show efficiencies calculated by the commonly used, old method, in which efficiencies are obtained simply from the ratio of the quantities of P_2O_5 recovered. Here, also, efficiencies based on the two kinds of data, weight of crop and weight of P_2O_5 recovered, agree fairly well for the most part. But when the efficiencies are much over 100, the use of data on crop increases evidently gives lower results than data of P_2O_5 recovered. The poor correspondence of high efficiencies is due to the fact that in these cases the method compares a large yield with a smaller one, and the percentage of P_2O_5 is usually higher in the large yields than in the smaller ones. The true efficiency value in these cases should be near the figures based on P_2O_5 recovered.

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DISCUSSION OF RESULTS

The preceding experiments indicate that several factors are involved in the effects of soil colloids on superphosphate; namely, the silica-sesquioxide ratio, the saturation of the colloid with P_2O_5, the effect of the colloid on the hydrogen-ion concentration of the medium, and the content of organic matter. The relative importance of these factors doubtless varies from colloid to colloid, but there are grounds for believing that as a rule the order of importance is as follows: Saturation with P_2O_5, silica-sesquioxide ratio, effect on hydrogen-ion concentration, and organic matter.

Degree of saturation with P_2O_5 is considered a more important factor than the silica-sesquioxide ratio in view of the following facts: There is practically no correspondence between silica-sesquioxide ratios and effects of the colloids on superphosphate until the colloids are separated into soil and subsoil materials, and the degree of saturation with P_2O_5 seems to be the feature chiefly responsible for the difference in the effects of soil and subsoil colloids.

The effect of the soil colloid on the hydrogen-ion concentration of the medium is obviously not so important a factor as the silica-sesquioxide ratio, for colloids that increase the efficiency of superphosphate markedly render the medium acid in some cases and neutral to alkaline in others. The same is true of colloids that markedly depress superphosphate efficiency. On the other hand, the highest efficiencies of superphosphate are associated with high silica-sesquioxide ratios in all instances, and the lowest efficiencies are associated with ratios below 2. Although less important on the whole than the silica-sesquioxide ratio, the hydrogen-ion concentration was shown to be of marked influence within certain ranges of the ratio. Sufficient soils were not tested to determine whether the influence was as marked for colloids with the highest ratios as for colloids with silica-sesquioxide ratios below 2.20.

Organic matter, if a factor in the effect of soil colloids on superphosphate, seems to be less important than the other factors. No relation is apparent between the organic content of colloids and efficiency values when soil and subsoil colloids are considered separately; nor can the more marked exceptions to the correspondence between silica-sesquioxide ratio and efficiency values be explained on the basis of organic content as well as by the influence of the hydrogen-ion concentration. Although these comparisons suggest that organic constitutents of the colloid have little effect on superphosphate, the direct experiments with organic materials gave very positive indications. The direct experiments, however, were not sufficiently extended to show in what measure the effects of organic materials are associated with different kinds and quantities of adsorbed ions other than H and OH. If the effect is largely dependent on the adsorbed ions, it would be difficult to divorce the effects of organic matter from those associated with the silica-sesquioxide ratio.

A study of the mechanism by which soil colloids promote or depress the efficiency of superphosphate was not undertaken in this investigation, but the data obtained have a bearing on this question even if they do not warrant definite conclusions.

Several facts indicate that the depressive effect of soil colloids on superphosphate cannot be ascribed primarily to precipitation in free

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solution by cations released from the colloids by base exchange with the fertilizer salts. The colloids that depress superphosphate most are those that have the smallest base-exchange capacity, this capacity following fairly closely the silica-sesquioxide ratio. The chief exchangeable cation of the colloids is calcium, and a considerable quantity of this is already present in salts of the base fertilizer and in the superphosphate itself. There is, of course, the possibility that those unsaturated colloids of low base-exchange capacity released exchangeable iron, aluminum, and manganese ions which precipitated the phosphate, but this seems improbable in view of the fact that the efficiency of superphosphate was found to be higher in the acid range where the exchange of iron and aluminum should be greater. On the other hand, the depressive effect of soil on superphosphate was influenced by the hydrogen-ion concentration in about the way one would predict from Gaarder's work showing how the hydrogen-ion concentration affects the solubility of PO_4 ions in the presence of various cations.

Although precipitation by ions in free solution may play a part in the depressive effect of some colloids, probably most of the effect is due to combination of the PO_4 ions with the iron and aluminium surfaces exposed by soil colloids. According to Weiser and Porter (*53*), and Bancroft and Ackerman (*7*), alumina gels combine either directly or by exchange, according to the condition of the gel. This mechanism would account for the various factors that seem to be involved in the depressive effects of soil colloids. Combination of phosphate ions would obviously be less in proportion as such surfaces are already saturated with phosphate and the quantity of PO_4 ions combined with increasing applications of phosphate would not be expected to show a sharp maximum. The iron and aluminum surfaces capable of combining with the phosphate would be expected to show some correspondence to the silica-sesquioxide ratio. The hydrogen-ion concentration would affect the quantity of PO_4 combined and the stability of the combination in the manner observed in the experiments on influence of the hydrogen-ion concentration. And finally, organic materials would be expected to promote rather than depress phosphate efficiency since they would be expected to offer a surface having some properties similar to those of silica.

Although the capacity of the colloid for fixing phosphate may be indicated by the silica-sesquioxide ratio, it is not necessarily sharply defined by the ratio, since the capacity could vary with both the reactivity and the extent of the iron and aluminum surfaces. This is suggested by the experiments with the extracted colloids of the Cecil subsoil in the fresh and year-old conditions. Also, a marked difference in the reactivity of fresh and aged artificial gels has been frequently observed.

According to the preceding hypothesis, soil colloids imparting a higher efficiency to superphosphate than pure quartz sand would present little if any unsaturated iron or aluminum surface to superphosphate. Also, the silica surface would necessarily have some activity in order to render it more effective than the inert quartz sand. This silica surface of the soil colloids would probably act on phosphates in the same way as the artificial silica gel and organic materials previously discussed. Having an affinity for cations, it

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could render phosphates more soluble in the film of contact between root and colloid particles by combining with precipitating ions.

Two general facts brought out in this investigation, the marked effects of soil colloids on superphosphate and the correspondence between these effects and the silica-sesquixide ratios, throw light on some previous laboratory investigations of soil phosphorus.

Recently, the effect of adding clays to sand cultures was studied by Blanck and Von Oldershausen (*8*). Notable differences in yield were produced by the clay applications, which they could ascribe only in part to the acid nature of the clay. Since there were no data to show that the phosphate supply was adequate, it seems probable that the results might have been due to the effects of the clays on the efficiency of the phosphate applied.

In connection with the relationship found between phosphate availability and the silica-sesquioxide ratio of soil colloids, it is interesting to note that a similar suggestion was made by Gans (*17*) some 20 years ago. According to Gans the availability of phosphates is dependent on a fixed relation between the silica-alumina and bases in the zeolitic part of the soil. An investigation by Tacke and Arnd (*46*) shows that the particular relationship suggested by Gans does not hold, but the results of this work show that Gans' basic idea of a relationship between colloid composition and phosphate availability was correct.

The favorable effects of high silica colloids observed in this work and the significance attributed to the so-called "soluble" silica found in soil extracts are doubtless related. According to McGeorge (*33*), Hawaiian soils which are well supplied with available phosphoric acid yield more silica to a 4 percent hydrochloric acid extraction than soils needing phosphate fertilizers. Hoffman (*25*) found a less close relation of fertilizer requirements to water soluble silica, but Němec's (*35*, *36*) work shows a close correspondence between water-soluble silica and the phosphate requirements indicated by the Neubauer test, also a correspondence between the phosphoric acid and the silica soluble in water extracts of soils. These correlations might be explained on the grounds that varying quantities of soluble silica indicate soil colloids of varying silica-sesquioxide ratios. As previously shown (table 7), the colloids high in silica have less capacity for fixing phosphoric acid, are presumably more nearly saturated, and therefore supply more available phosphoric acid.

Certain laboratory methods of estimating the phosphate requirements of soils seem to recognize empirically the widely varying capacities of soil colloids for rendering phosphates unavailable. According to the citric acid method, a soil needs phosphate fertilization not only when citric-acid-soluble phosphoric acid falls below a certain value, but also when the citric-acid-soluble P_2O_5 is less than 25 percent of the total P_2O_5 soluble in strong acid. The supposition has not been tested, but one would expect that a lower percentage of the total phosphoric acid would be soluble in weak acid, the lower the silica-sesquioxide ratio of the colloidal soil material; for the lower the ratio the greater the capacity for fixing phosphate. Němec's (*37*) observation that phosphatic fertilizers do not exert their full effect on soils yielding more than 50 mg of citrate soluble iron per 100 g of soil probably could be similarly explained on the grounds that such soils

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contain low silica-sesquioxide ratio colloids which have a high capacity for fixing phosphoric acid and are likely to be unsaturated.

Truog's (*49*) method of estimating available phosphoric acid calls for digestion of the soil with H_2SO_4 adjusted to a pH of 3.0. The concentration of P_2O_5 in solution at this acidity, according to Gaarder's (*16*) data would be governed by the comparative amounts of P_2O_5 and iron dissolved, modified to some extent by the presence of silica, alumina, and iron gels. The quantity of P_2O_5 dissolved, as shown by Engels' (*12*) data combined with that of Rauterberg (*42*) would be greater the more nearly the soil is saturated with P_2O_5. The quantity of iron dissolved one would expect to be greater the lower the silica-sesquioxide ratio of the colloid, and Robinson and Holmes' data (*44*) for a few colloids indicate this is the case. It would follow, then, that when Truog's method is applied to soils containing colloids of similar silica-sesquioxide ratios, it should show comparative degrees of saturation with P_2O_5 or comparative availability of the P_2O_5. And when the method is applied to soils containing colloids of different silica-sesquioxide ratios, the results would reflect the kind of colloid present fully as much as the degree of saturation.

The main facts brought out in this investigation have a bearing on the practical use of phosphatic fertilizers.

The low efficiency shown by superphosphate in the presence of soil colloids with low silica-sesquioxide ratios, and the high efficiency shown in the presence of colloids with high ratios is in general accord with practical experience in the use of superphosphate. The greater part of the superphosphate produced in the United States is consumed in the southeastern and eastern parts of the country, and in these regions colloids with low silica-sesquioxide ratios predominate, so far as can be judged from the available data of Robinson and Holmes (*44*) and of Byers and Anderson (*2*, *11*). Many factors affect this large consumption of superphosphate, but it seems probable that no inconsiderable fraction of the phosphate used in these regions goes toward saturating the soil with phosphoric acid. In the Middle West, where the soil colloids are as a rule higher in silica, less superphosphate is used per acre. Here, also, factors such as rainfall, economic conditions, and prevailing crops doubtless contribute toward smaller applications. But a higher efficiency of the superphosphate is evidently likewise a factor, for crop increases produced in this region with small amounts of phosphates are often notably large, as compared with those produced in the East and Southeast.

The capacity shown by the Brazil and Nipe soils for rendering normal applications of superphosphate practically ineffective is suggestive. Evidently comparatively enormous applications of superphosphates would be needed to attain a moderate availability of added phosphate in such soils. A normal application of superphosphate would probably produce such small crop increases on these soils that one lacking information regarding the high fixing power of the soils would naturally conclude that the soils did not need phosphatic fertilizers. A survey made of agricultural soils containing colloids of low silica-sesquioxide ratios might show considerable areas of soil in the United States so unsaturated with phosphoric acid and of such high capacity for fixing added phosphate that fair productivity could only be obtained through heavy phosphatic fertilization.

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The experiments made with comparatively few subsoils in this investigation indicate that a condition of low phosphoric acid saturation, and consequent low phosphate availability, is rather general for subsoils where the silica-sesquioxide ratio of the colloid is not above 2. This suggests the need for exceptionally heavy applications of phosphatic fertilizers where such subsoils are exposed, as in eroded areas. Estimates of the extent of soil erosion indicate that subsoil fertilization may become an important economic problem. Although nitrogen has usually been considered the chief fertilizer requirement of subsoils, a few investigators have pointed out the need for phosphates. Possibly the long time usually required for building up the productivity of subsoils is owing to an inadequate use of phosphates. If, at the start, sufficient phosphoric acid were applied to feed the soil as well as the crop, it might be that the time required to restore the productivity of subsoils to that of surface soils could be considerably shortened.

The silica-sesquioxide ratio of the soil colloids may prove to be a good indicator of areas where special methods of fertilizer distribution are important. If the soil colloids are of the kind that depress the efficiency of superphosphate, it would seem desirable to apply the phosphate in such a manner as to minimize this effect. The few tests conducted in this study suggest that this may be accomplished by applying the phosphate in a restricted zone near the seed. On the other hand, if the soil tends to enhance the efficiency of superphosphate, possibly equally as good results may be obtained with a more uniform distribution (table 3).

SUMMARY

This investigation deals with the effects of different colloidal soil materials on the efficiency of superphosphate. The effects are determined by comparing the growth made by millet (*Setaria italica*) in pure quartz sand with the growth made in sand to which sufficient soil is added to supply 1 percent of colloidal material. Data of some 1,400 pots are reported.

The addition of some soils to quartz sand reduces the efficiency of superphosphate. The reduction in efficiency is greater, the larger the soil application, and less, the larger the application of superphosphate.

Efficiency of the superphosphate also varies with the method of application, applications confined to a 1-inch layer below the seed producing larger yields than applications uniformly mixed with the whole mass of sand and soil.

When soils with depressing effects are present, the efficiency of superphosphate seems to be highest at a pH of 4.5 to 5.0 and lowest in the neighborhood of neutrality.

Comparison of the effects of isolated colloidal and noncolloidal soil fractions indicates that the effects of soil on the efficiency of superphosphate are largely localized in the colloidal fraction. The comparison, however, is somewhat imperfect, presumably owing to contamination of the noncolloidal fraction with copper or other heavy metals.

Determinations are given of the effects of 17 surface soils and 14 subsoils on the efficiency of superphosphate. The effects of the

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different soils vary remarkably. If an efficiency of 100 percent is assumed for the efficiency of superphosphate in pure quartz sand, additions of some soils reduce the efficiency to 1 percent, whereas others raise the efficiency to 148 and 198 percent. Thirteen of the fourteen subsoils tested impart a lower efficiency than the corresponding surface soils.

The effects of surface soils on superphosphate correlate fairly well with the silica-sesquioxide ratios of the colloids present, soils containing colloids with high silica-sesquioxide ratios enhancing the efficiency of superphosphates and those containing colloids with low ratios depressing efficiency. The same is true of subsoil materials also.

Determinations of the effect of two purely organic colloids, activated charcoal and peat, are also reported. These increase the efficiency of superphosphate and rock phosphate in pure quartz sand and the efficiency of superphosphate in sand and soil mixtures.

The effect of a soil colloid on superphosphate seems to depend on several factors, namely, the degree to which the colloidal material is saturated with phosphoric acid, the silica-sesquioxide ratio of the colloid, the effect of the colloid on the hydrogen-ion concentration of the medium, and the content of organic matter. The relative importance of the different factors is believed to be in the order given, the first mentioned being most important. The manner in which the various factors affect superphosphate is discussed.

The availability of rock phosphate, on the other hand, seems to be governed primarily by the hydrogen-ion concentration of the medium, but within the acid range other factors may influence the availability of this material.

The efficiencies of superphosphate calculated from the weights of crop increases are about the same as those calculated from the quantities of phosphoric acid recovered in the crops.

The observed effects of soil colloids on superphosphate are discussed in their relation to known laboratory methods of determining available phosphoric acid and in their bearing on actual fertilizer practice.

LITERATURE CITED

(1) Anderson, M. S.
1929. the influence of substituted cations on the properties of soil colloids. Jour. Agr. Research 38:565–584.

(2) ——— and Byers, H. G.
1931. character of the colloidal materials in the profiles of certain major soil groups. U.S. Dept. Agr. Tech. Bul. 228, 24 p.

(3) ——— Fry, W. H., Gile, P. L., Middleton, H. E., and Robinson, W. O.
1922. absorption by colloidal and noncolloidal soil constituents. U.S. Dept. Agr. Bul. 1122, 20 p.

(4) ——— and Mattson, S.
1926. properties of the colloidal soil material. U.S. Dept. Agr. Bul. 1452, 47 p., illus.

(5) Association of Official Agricultural Chemists.
1925. official and tentative methods of analysis. compiled by the committee on editing methods of analysis. revised to july 1, 1924. Ed. 2, 335 p., illus. Washington, D.C.

(6) Ayres, A. H.
1917. influence of the composition and concentration of the nutrient solution on plants grown in sand cultures. Calif. Univ. Pubs., Agr. Sci. 1, [341]–394, illus.

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(7) BANCROFT, W. D., and ACKERMAN, J. W.
1931. ALUMINA AS AN IONIZING ADSORBENT. Jour. Phys. Chem. 35:[2568]–2580.
(8) BLANCK, E., and OLDERSHAUSEN, E. VON.
1930. ÜBER DEN EINFLUSS EINES ZUSATZES VON TON VERSCHIEDENER ZUSAMMENSETZUNG ZU SAND AUF DAS PFLANZENWACHSTUM. Jour. Landw. 77:[331]–336, illus.
(9) BREAZEALE, J. F., and MCGEORGE, W. T.
1932. NUTRITIONAL DISORDERS IN ALKALINE SOILS AS CAUSED BY DEFICIENCY OF CARBON DIOXIDE. Ariz. Agr. Expt. Sta. Tech. Bul. 41, p. [113]–153, illus.
(10) BROWN, I. C., and BYERS, H. G.
1932. THE FRACTIONATION, COMPOSITION, AND HYPOTHETICAL CONSTITUTION OF CERTAIN COLLOIDS DERIVED FROM THE GREAT SOIL GROUPS. U.S. Dept. Agr. Tech. Bul. 319, 44 p.
(11) BYERS, H. G., and ANDERSON, M. S.
1932. THE COMPOSITION OF SOIL COLLOIDS IN RELATION TO SOIL CLASSIFICATION. Jour. Phys. Chem. 36:[348]–366.
(12) ENGELS, O.
1931. UNTERSUCHUNGEN ÜBER DEN LÖSLICHKEITSGRAD DER PHOSPHORSAÜRE (RELATIVE LÖSLICHKEIT) IN DER ACKERKRUME UND DEM UNTERGRUND VERSCHIEDENER BODENARTEN. Ztschr. Pflanzenernähr. u. Düngung (B) 10:181–187.
(13) FEUSTEL, I. C., and BYERS, H. G.
1930. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF CERTAIN AMERICAN PEAT PROFILES. U.S. Dept. Agr. Tech. Bul. 214, 27 p., illus.
(14) FORBES, R. H.
1917. CERTAIN EFFECTS UNDER IRRIGATION OF COPPER COMPOUNDS UPON CROPS. Calif. Univ. Pubs., Agr. Sci. 1:395–494, illus.
(15) FORD, M. C.
1932. THE DISTRIBUTION, AVAILABILITY, AND NATURE OF THE PHOSPHATES IN CERTAIN KENTUCKY SOILS. Jour. Amer. Soc. Agron. 24: 395–410.
(16) GAARDER, T.
1930. DIE BINDUNG DER PHOSPHORSÄURE IN ERDBODEN. Meddel. Vestlandets Forstl. Forsokssta. Bd. 4, Heft. 4, 140 p., illus.
(17) GANS, R.
1914. DIE CHARAKTERISIERUNG DES BODENS NACH DER MOLEKULAREN ZUSAMMENSETZUNG DES DURCH SALZSÄURE ZERSETZLICHEN SILIKATISCHEN ANTEILS (DER ZEOLITITHISCHEN SILIKATE). Jahrb. K. Preuss. Geol. Landesanstalt 35 (teil 1):[219]–255.
(18) GEDROIZ, K.
1911. AUF WELCHEN BÖDEN WIRKT DER PHOSPHORIT. DIE MIT BASEN GESÄTTIGTEN UND UNGESÄTTIGTEN BÖDEN. Zhur. Opytn. Agron. Ingo-Vostoka (Jour. Expt. Landw. Südost, Eur.-Russlande) 12:[529]–546. [In Russian. German résumé, p. 539–546].
(19) GERICKE, S.
1928. DIE VERTEILUNG VON PHOSPHORSAURE UND KALI IN BODEN. Ztschr. Angew. Chem. 41:52–56.
(20) GILE, P. L., and CARRERO, J. O.
1916. A PLAN FOR TESTING EFFICIENCIES OF FERTILIZERS. Jour. Amer. Soc. Agron. 8:247–255, illus.
(21) ——— and CARRERO, J. O.
1923. EFFICIENCIES OF PHOSPHATIC FERTILIZERS AS AFFECTED BY LIMING AND BY THE LENGTH OF TIME THE PHOSPHATES REMAINED IN PORTO RICAN SOILS. Jour. Agr. Research 22:171–194, illus.
(22) ——— MIDDLETON, H. E., ROBINSON, W. O., FRY, W. H., and ANDERSON, M. S.
1924. ESTIMATION OF COLLOIDAL MATERIAL IN SOILS BY ADSORPTION. U.S. Dept. Agr. Bul. 1193, 42 p.
(23) ——— and SMITH, J. G.
1925. COLLOIDAL SILICA AND THE EFFICIENCY OF PHOSPHATES. Jour. Agr. Research 31:247–260, illus.

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(24) HASENBÄUMER, J., and BALKS, R.
1930. GEHALT UND LÖSCHLICHKEIN VON KALI UND PHOSPHORSÄURE IN ACKERKRUME UND UNTERGRUND VON BÖDEN DER VERSCHIEDENEN BODENKLASSEN. Ztschr. Pflanzenernähr. u. Düngung (B) 9:97–109.

(25) HOFFMANN, E.
1930. STUDIEN ÜBER DIE LÖSLICHKEIT DER BODENPHOSPHORSÄURE UND KIESELSÄURE ALS GRUNDLAGE FÜR DIE BESTIMMUNG DES PHOSPHORSÄUREBEDÜRFNISSES. Landw. Jahrb. 72:791–834.

(26) HOFFMANN, M.
1921. ZUR FRAGE DES PHOSPHATDÜNGER-PROBLEMS. Biedermann's Zentbl. 50:370–372.

(27) HOLMES, R. S., and EDGINGTON, G.
1930. VARIATIONS OF THE COLLOIDAL MATERIAL EXTRACTED FROM THE SOILS OF THE MIAMI, CHESTER, AND CECIL SERIES. U.S. Dept. Agr. Tech. Bul. 229, 24 p., illus.

(28) HONCAMP, F., and STEINFATT, F.
1927. UEBER DEN NÄHRSTOFFGEHALT VON ACKERKRUME UND UNTERGRUND UND SEINE BEDEUTUNG FÜR DIE UNTERSUCHUNG DER BÖDEN. Ztschr. Pflanzenernähr. u. Düngung. (B) 6:21–27.

(29) JESSEN, W., and LESCH, W.
1930. UBER DEN EINFLUSS VON KIESELSÄURE, TORF UND HUMUS AUF DIE LÖSLICHKEIT UND AUFNAHME DER PHOSPHORSÄURE. Ztschr. Pflanzenernähr. u. Düngung (A) 17:48–66.

(30) KLING, M., and ENGELS, O.
1925. VERGLEICHENDE UNTERSUCHUNGEN ÜBER DEN NACH DEM NEUBAUER'SCHEN VERFAHREN ERMITTELTEN GEHALT DES BODENS AN PHOSPHORSÄURE UND KALI IN ACKERKRUME UND UNTERGRUND. Ernahr. Pflanze 21:141–142.

(31) LEMMERMANN, O. and WIESSMANN, H.
1924. WEITERE VERSUCHE ÜBER DIE ERTRAGSSTEIGERNDE WIRKUNG DER KIESELSÄURE BEI UNZUREICHENDER PHOSPHORSÄUREDÜNGUNG. Ztschr. Pflanzenernähr. u. Düngung (B) 3:[185]–197.

(32) MATTSON, S.
1928. THE ACTION OF NEUTRAL SALTS ON ACID SOILS WITH REFERENCE TO ALUMINUM AND IRON. Soil Sci. 25:345–350.

(33) MCGEORGE, W. T.
1923. A STUDY OF THE PHOSPHATES IN THE ISLAND SUGAR LANDS. Hawaii. Sugar Planters' Assoc. Agr. and Chem. Ser. Bul. 47, 51 p., illus.

(34) ———
1932. ELECTRODIALYSIS AS A MEASURE OF PHOSPHATE AVAILABILITY IN SOILS AND THE RELATION OF SOIL REACTION AND IONIZATION OF PHOSPHATES TO PHOSPHATE ASSIMILATION. Ariz. Agr. Expt. Sta. Tech. Bul. 38, p. [593]–630, illus.

(35) NĚMEC, A.
1928. DETERMINATION DES BESOINS DES SOLS EN ACIDE PHOSPHORIQUE D'APRÈS LA SILICE SOLUBLE. Compt. Rend. Acad. Sci. [Paris] 186:1060–1062.

(36) ———
1930. BEITRAG ZUR FRAGE DES EINFLUSSES VON KIESELSÄURE AUF DIE RESORPTION DER BODENPHOSPHORSÄURE. Ztschr. Pflanzenernähr. u. Düngung (A) 15:258–262.

(37) ———
1930. EIN NEUES VERFAHREN ZUR AUSWERTUNG CHEMISCHER DÜNGUNGSBEDÜRFTIGKEITSMETHODEN AUF DIE BESTIMMUNG DER WIRKUNG PHOSPHORSÄUREHALTIGER DÜNGEMITTEL. Ztschr. Pflanzenernähr. u. Düngung (A) 18:48–56.

(38) PFEIFFER, T., and BLANCK, E.
1911. ÜBER DIE WIRKUNG EINES ZUSATZES VON TONERDE-UND KIESELSÄUREGEL ZUM BODEN AUF DIE AUSNUTZUNG DER PHOSPHORSÄURE DURCH DIE PFLANZEN. Mitt. Landw. Inst. Breslau 6:[315]–324.

(39) ——— and SIMMERMACHER, W.
1916. VERGLEICHERDE VERSUCHE ÜBER DIE AUSNUTZUNG DER PHOSPHORSÄURE UND DES STICKSTOFFS DURCH DIE PFLANZEN. Landw. Vers. Sta. 88:[445]–463, illus.

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(40) PRIANISCHNIKOW, D.
1907. ZUR FRAGE ÜBER DEN RELATIVEN WERT VERSCHIEDENER PHOSPHATE. Landw. Vers. Sta. 65:[23]–54, illus.

(41) ———
1911. ÜBER DEN EINFLUSS VON KOHLENSAUREM KALK AUF DIE WIRKUNG VON VERSCHIEDENEN PHOSPHATEN. Landw. Vers. Sta. 75:[357]–376, illus.

(42) RAUTERBERG, E.
1931. UEBER DIE BERUCKSICHTIGUNG DER BODENART BEI DEN UNTERSUCHUNGEN DER BODEN AUF IHRE PHOSPHORSÄUREBEDURFTIGKEIT. Ztschr. Pflanzenernähr. u. Düngung (A) 20:302–356.

(43) ROBINSON, W. O.
1922. THE ABSORPTION OF WATER BY SOIL COLLOIDS. Jour. Phys. Chem. 20:647–653.

(44) ——— and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U.S.Dept.Agr. Bul. 1311, 42 p.

(45) SCARSETH, G. D.
1932. MORPHOLOGICAL, GREENHOUSE, AND CHEMICAL STUDIES OF THE BLACK BELT SOILS OF ALABAMA. Ala. Agr. Expt. Sta. Bul. 237, 48 p., illus.

(46) TACKE, B., and ARND.
1923. PHYSIKALISCHE UND CHEMISCHE STUDIEN AN SCHWEREN TONBÖDEN. Internatl. Mitt. Bodenk. 13:6–26.

(47) TEAKLE, L. J. H.
1928. PHOSPHATE IN THE SOIL SOLUTION AS AFFECTED BY REACTION AND CATION CONCENTRATIONS. Soil Sci. 25:143–162, illus.

(48) THOM, C., and HUMFELD, H.
1932. NOTES ON THE ASSOCIATION OF MICROÖRGANISMS AND ROOTS. Soil Sci. 34:29–36.

(49) TRUOG, E.
1903. THE DETERMINATION OF THE READILY AVAILABLE PHOSPHORUS OF SOIL. Jour. Amer. Soc. Agron. 22:874–883.

(50) WAGNER, P., and DORSCH, R.
1892. DIE STICKTOFFDÜNGUNG DER LANDWIRTSCHAFTLICHEN KULTURPFLANZEN. 441 p. Berlin.

(51) WAGNER, P., DORSCH, R., RUTHS, H., and HAMANN, G.
1904. VERSUCHE ÜBER DIE KALIDÜNGUNG DER KULTURPFLANZEN. Arb. Deut. Landw. Gesell. Heft 96, 422 p.

(52) WARINGTON, R., JR.
1868. ON THE PART TAKEN BY OXIDE OF IRON AND ALUMINA IN THE ABSORPTIVE ACTION OF SOILS. Jour. Chem. Soc. [London] 21:1–19.

(53) WEISER, H. B., and PORTER, E. E.
1927. THE PHYSICAL CHEMISTRY OF COLOR LAKE FORMATION. III. ALIZARIN LAKES. Jour. Phys. Chem. 31:[1824]–1839, illus.

(54) WIEGNER, G.
1930. UEBER WASSERSTOFF- UND HYDROXYLIONEN IN DEN IONENSCHWÄRMEN UM SUSPENDIERTE TEILCHEN UND DISPERGIERTE ULTRAMIKRONEN. Kolloid Ztschr. 51:49–60, illus.

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APPENDIX

Tables 11–31 are those from which the composite tables (1–10) in the text have been derived. Although considerable reference is made in the text to tables 11–31 the significance of the data which they contain is enhanced by their consolidation in those tables which appear in logical sequence in the text. In order to avoid an excess of tabulation throughout the text, while giving the necessary data of the individual tables, and demonstrating the steps by which the more significant composite tables have been derived, tables 11–31 have been placed in this Appendix.

TABLE 11.—*Applications of superphosphate and soil in layers compared with applications mixed uniformly with all the sand; effect of omitting Mn from the base fertilizer; influence of quantity of soil on the efficiency of superphosphate; effect of mixing a soil (Sharkey) enhancing phosphate efficiency with a soil (Brazil) depressing efficiency* [1]

Kind of base fertilizer	P_2O_5 applied per pot	Manner in which superphosphate applied	Soil mixed with quartz sand [2]	Average oven-dry yield per pot of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram			*Grams*	*Gram*	*Percent*
No. 1	0		None	0.14	0	
	.04	Uniformly	do	.60	.05	100
	.08	do	do	.82	.10	100
	.12	do	do	1.34	.05	100
	.18	do	do	2.17	.15	100
No. 1, Mn omitted	.04	do	do	.94	.02	220
	.12	do	do	1.92	.03	135
No. 1	.04	In layer	do	1.51	.04	332
	.12	do	do	2.46	.05	168
	.12	Uniformly	Brazil soil, supplying 50 g of colloid.	.31	.02	13
	.12	do	Brazil soil, supplying 25 g of colloid.	.78	.02	61
	.12	do	Brazil soil, supplying 12½ g of colloid.	1.06	.06	82
	.12	do	Brazil and Sharkey, supplying 25 g of colloid each.	.90	.03	72
	.12	In layer	Brazil soil supplying 50 g of colloid, applied in a layer.	1.71	.08	123

[1] All treatments replicated 4 times. [2] Quantity expressed in terms of colloid content.

TABLE 12.—*Different base fertilizers for quartz sand compared*

(Applications of superphosphate in layers compared with those mixed uniformly with all the sand) [1]

Kind of base fertilizer	P_2O_5 applied per pot	Manner in which the superphosphate mixed with the quartz sand	Average oven-dry yield per pot of plants above-ground	Probable error of average	Efficiency of superphosphate [2]
	Gram		*Grams*	*Gram*	*Percent*
No. 2, standard	0		0.20	0	
	.06	Uniformly	2.98	.11	100
	.12	do	4.40	.11	100
	.18	do	4.72	.11	100
	.06	In layer	3.26	.06	120
No. 3, Fe and Mn omitted	.06	Uniformly	2.94	.03	100
	.06	In layer	3.69	.02	150
No. 4, double Fe	.06	Uniformly	2.57	.09	87
	.06	In layer	2.92	.19	97
No. 5, Ca and Mg reduced	.06	Uniformly	2.89	.07	97
	.06	In layer	3.25	.10	120

[1] All treatments replicated 4 times.
[2] Superphosphate uniformly mixed and used with standard fertilizer taken as 100 percent.

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TABLE 13.—*Effect of precipitated calcium carbonate on growth in quartz sand with standard base fertilizer* [1]

Treatment with calcium carbonate	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot of plants aboveground	Probable error of the average
	Gram		*Grams*	*Gram*
None	0	4.5	0.78	0.06
	.03	4.7	1.49	.05
	.06	4.7	1.63	.03
	.12	4.7	1.66	.07
$CaCO_3$, 0.4 g per pot [2]	0	6.7	.45	.01
	.03	6.9	1.13	.14
	.06	6.9	1.72	.08
	.12	6.9	1.89	.05
$CaCO_3$, 0.8 g per pot [2]	0	7.4	.47	.03
	.03	7.4	1.03	0
	.06	7.4	1.48	.04
	.12	7.4	1.70	.02
$CaCO_3$, 1.6 g per pot [2]	0	8.0	.34	.02
	.03	7.8	.83	.02
	.06	8.0	1.22	.07
	.12	8.0	1.46	.03

[1] All treatments replicated 3 times.
[2] Plants in series receiving $CaCO_3$ slightly chlorotic at times; chlorosis most pronounced with 1.6 g of $CaCO_3$.

TABLE 14.—*A comparison of different base fertilizers* [1]

Base fertilizer no.	Special features of base fertilizer		Soil added at rate of 25 g of colloid per pot	pH of medium after growth	Average oven-dry yield per pot of plants aboveground	Probable error of the average
	Source of nitrogen	Special salts added				
					Grams	*Gram*
2	½ NH_4, ½ NO_3	None	None	4.9	2.56	0.04
6	do	NaCl	do		2.30	.06
		do	Sharkey	4.9	2.56	.06
		NaCl+0.66 g of $NaHCO_3$	None	7.5	1.68	.04
		NaCl+1.31 g of $NaHCO_3$	do		.91	.04
7	All NO_3	None	do		2.00	.04
8	do	CuCl, H_3BO_3	do	7.3	2.18	.06
		do	Sharkey	6.9	2.49	.04
		CuCl, H_3BO_3+0.66 g of $NaHCO_3$.	None	8.8	1.21	.05
		CuCl, H_3BO_3+0.31 g of $NaHCO_3$.	do		.30	.01

[1] Each pot received 1.2 g of P_2O_5 from superphosphate; all treatments replicated 3 times.

TABLE 15.—*Concentration of the base fertilizer as a factor influencing the extent that soil additions lower the efficiency of superphosphates* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth—		Average oven-dry yield, per pot, of plants aboveground			
		With standard base fertilizer	With one half standard base fertilizer	With standard base fertilizer	Probable error of average	With one half standard base fertilizer	Probable error of average
	Gram			*Gram*	*Gram*	*Gram*	*Gram*
None	0	6.6	6.6	0.11	0	0.12	0
	.05	4.7	5.3	.39	.04	.41	.02
	.10	5.7	5.9	.52	.02	.48	.04
Nipe	0	6.9	6.4	.09	0	.08	0
	.10	6.3	6.3	.12	.01	.12	0
	.20	6.5	6.5	.18	0	.18	.01

[1] All treatments replicated 4 times. Nipe soil added at rate of 50 g of colloid per pot.

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TABLE 16.—*Effects of different soils on the efficiencies of superphosphate and rock phosphate in quartz sand. Applications of phosphate and colloid, in 1-inch layers, compared with applications uniformly mixed with all the sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	Kind of phosphate applied	Manner in which phosphate or phosphate and soil was mixed with sand	Average oven-dry yield per pot, of plants above-ground	Probable error of average	Efficiency of superphosphate
	Gram			*Grams*	*Gram*	*Percent*
None	0	None		0.14	0	
	.06	Super	Uniformly	2.99	.11	100
	.09	do	do	4.25	.12	100
	.12	do	do	5.16	.06	100
	.18	do	do	6.24	.06	100
	.06	do	In layer	2.77	.20	95
	.36	Rock	Uniformly	.15	0	0
	.36	do	In layer	.16	.01	0
Cecil soil	0	None		.12	0	
	.12	Super	Uniformly	3.99	.18	70
	.36	Rock	do	.13	.01	0
Cecil subsoil	0	None		.10	0	
	.12	Super	Uniformly	.90	.08	14
	.06	do	In layer	1.78	.16	60
	.36	Rock	Uniformly	.10	0	0
	.36	do	In layer	.12	0	0
Sassafras soil	0	None		.12	0	
	.12	Super	Uniformly	5.37	.16	111
	.36	Rock	do	.12	0	0
Sassafras subsoil	0	None		.13	0	
	.12	Super	Uniformly	2.75	.12	46
	.36	Rock	do	.17	.01	0
Fallon soil	0	None		.21	.01	
	.06	Super	Uniformly	2.87	.15	[2] 95+
	.12	do	do	4.45	.25	[2] 78+
	.36	Rock	do	.23	.01	0

[1] All treatments replicated 4 times. All soil applications at rate of 50 g of colloid per pot. pH about 7.5, except where Fallon soil added, pH about 8.0.
[2] Plants chlorotic and limited in growth owing to a deficient assimilation of iron.

TABLE 17.—*Efficiency of superphosphate in a mixture of Nipe soil and quartz sand, as affected by the quantities of soil and superphosphate* [1]

[The sand contained some P_2O_5 as impurity]

Rate at which Nipe soil applied, calculated as grams of colloid per pot (grams)	P_2O_5 applied per pot	Average oven-dry yield per pot of plants above-ground	Probable error of the average	Total P_2O_5 per pot on assumption sand contained 0.015 g of available P_2O_5 [2]	Efficiency of total P_2O_5 on assumption sand contained 0.015 g of available P_2O_5
	Gram	*Grams*	*Gram*	*Gram*	*Percent*
None	0	2.01	0.18	0.015	100
	.03	4.46	.09	.045	100
	.06	5.18	.11	.075	100
	.12	5.51	.10	.135	100
	.18	5.67	.11	.195	
50	0	.09	0	.015	0
50	.12	1.82	.16	.135	10
50 [3]	[3] .12	4.74	.05	.135	42
50	.24	4.66	.27	.255	21
25	.06	1.57	.08	.075	15
	.12	4.32	.04	.135	32
	.24	5.97	.09	.255	
12½	.03	1.56	.14	.045	24
	.06	3.32	.12	.075	41
	.12	5.32	.03	.135	75

[1] All treatments replicated 4 times.
[2] This quantity arrived at by plotting curve of increased growth against increased applications of superphosphate and then projecting curve beyond the origin to the point for a 0.1-g crop. Other experiments indicate that 0.1 g is the approximate weight of crop when no P_2O_5 is present.
[3] Colloid and phosphate applied in a 1-inch layer, one fourth inch below seed.

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TABLE 18.—*Efficiency of superphosphate in a mixture of Nipe soil and quartz sand, as affected by the quantity of soil and of superphosphate* [1]

Kind of soil mixed with quartz sand, and quantity in terms of colloid content	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield, per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram		*Grams*	*Gram*	*Percent*
None	0	5.9	0.28	0.02	----------
	.025	4.9	2.08	.02	100
	.050	5.0	3.12	.06	100
	.100	5.0	4.06	.06	100
Nipe soil, 100 g of colloid	0	6.2	.05	0	----------
	.050	6.5	.06	0	----------
Nipe soil, 50 g of colloid	0	6.5	.06	0	----------
	.050	----------	.10	.01	1
	.100	----------	.29	.02	3.5
	.150	----------	.68	.06	6
	.200	5.4	1.19	.04	8
Nipe soil, 25 g of colloid	0	6.5	.07	0	----------
	.050	6.0	.20	.02	4
Nipe soil, 12½ g of colloid	0	6.7	.08	0	----------
	.050	4.7	.81	.04	21

[1] All treatments replicated 4 times.

TABLE 19.—*Colloidal and noncolloidal fractions of Cecil subsoil compared as to their effects on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram		*Grams*	*Gram*	*Percent*
None	0	6.5	0.09	0.01	----------
	.025	4.1	1.33	.07	100
	.050	4.1	2.09	.17	100
	.100	4.3	2.47	.13	100
Untreated soil, at rate of 20 g of colloid	0	6.0	.06	0	----------
	.150	4.1	3.03	.13	100
Untreated soil, at rate of 40 g of colloid	0	6.5	.07	0	----------
	.150	4.1	1.83	.21	28
Untreated soil, at rate of 60 g of colloid	0	6.5	.06	0	----------
	.150	4.2	1.31	.10	17
Extracted colloid, 40 g	0	6.7	.07	.01	----------
	.150	6.2	.89	.13	11
Noncolloidal residue, 47 g	0	6.7	.09	0	----------
	.150	6.2	1.15	.08	14
20 g of extracted colloid, 24 g of residue colloid	0	6.7	.07	0	----------
	.150	4.5	1.53	.22	22

[1] All treatments replicated 4 times.

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TABLE 20.—*Colloidal and noncolloidal fractions of Cecil subsoil compared, 1 year after separation, as to their effects on the efficiency of superphosphate in quartz sand* [1]

Kind and quantity of soil mixed with quartz sand	P_2O_5 applied per pot	Average oven-dry yield, per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram	*Grams*	*Gram*	*Percent*
None	0	0.07	0	
	.05	3.84	.07	100
	.10	4.94	.13	100
Untreated soil at rate 10 g of colloid	0	.07	0	
	.05	2.11	.02	55
Untreated soil at rate 20 g of colloid	0	.06	0	
	.05	1.25	.04	32
Untreated soil at rate 40 g of colloid	0	.07	0	
	.05	.48	.05	11
Untreated soil at rate 80 g of colloid	0	.07	0	
	.05	.20	0	3
Extracted colloid, 20 g	0	.08	0	
	.05	1.36	.06	34
Noncolloidal residue, 40 g	0	.08	0	
	.05	2.31	.14	62

[1] No-phosphate treatments not replicated; other treatments replicated 3 times.

TABLE 21.—*Colloidal and noncolloidal fractions of Sassafras subsoil compared as to their effects on the efficiency of superphosphate in quartz sand* [1]

Kind and quantity of soil mixed with quartz sand	P_2O_5 applied per pot	Average oven-dry yield, per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram	*Grams*	*Gram*	*Percent*
None	0	0.06	0	
	.025	1.68	.06	100
	.050	3.65	.12	100
	.100	4.73	.06	100
Untreated soil at rate 15 g of colloid	0	.07		
	.050	2.24	.08	64
Untreated soil at rate 30 g of colloid	0	.10		
	.050	1.22	.09	34
Untreated soil at rate 60 g of colloid	0	.09		
	.050	.47	.02	12
Untreated soil at rate 120 g of colloid	0	.10		
	.050	.21	0	4
Extracted colloid, 40 g	0	.08	0	
	.050	.36	.03	8
Noncolloidal residue, 40 g	0	.08		
	.050	1.82	.09	52
	0	.08		
	.050	1.42	.09	42
20 g extracted colloid and 40 g of noncolloidal residue	0	.08		
	.050	.71	.04	20
Untreated soil at rate 60 g of colloid	.025	.14	0	4
	.100	2.90	.06	41
	.150	5.07	.11	77

[1] No-phosphate treatments not replicated; other treatments replicated 4 times.

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TABLE 22.—*Colloidal and noncolloidal fractions of Clarksville subsoil compared as to their effects on the efficiency of superphosphate in quartz sand* [1]

Kind and quantity of soil mixed with quartz sand	P_2O_5 applied per pot	Average oven-dry yield, per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram	*Grams*	*Gram*	*Percent*
None	0	0.07	0	----------
	.025	1.29	.07	100
	.050	2.15	.19	100
	.100	4.34	.22	100
Untreated soil at rate 20 g of colloid	0	.06	----------	----------
	.050	1.57	.05	66
Untreated soil at rate 40 g of colloid	0	.07	----------	----------
	.050	1.03	03	40
Untreated soil at rate 80 g of colloid	0	.07	----------	----------
	.050	.51	.03	20
Extracted colloid, 40 g	0	.08	----------	----------
	.050	.19	.01	4
Noncolloidal residue, 40 g	0	.07	----------	----------
	.050	1.19	.10	46
Untreated soil at rate of 120 g	0	.07	----------	----------
	.050	.70	.05	28
20 g of extracted colloid and 60 g of noncolloidal residue	0	.08	----------	----------
	.050	.38	.03	14
Untreated soil at rate of 40 g of colloid	.025	.17	----------	8
	.100	3.77	.07	86

[1] No-phosphate treatments not replicated; other treatments replicated 4 times.

TABLE 23.—*Effects of different soils on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate
	Gram		*Grams*	*Gram*	*Percent*
None	0	4.8	0.36	0.04	----------
	.06	----------	2.76	.04	100
	.12	4.7	2.89	.04	----------
	.18	----------	2.96	.07	----------
Huntington soil	0	4.6	.89	.05	----------
	.06	4.6	2.62	.12	72
Huntington subsoil	0	4.7	.23	.01	----------
	.12	4.6	2.13	.06	40
Norfolk soil	0	4.8	.23	.01	----------
	.12	4.8	1.39	.14	24
Norfolk subsoil	0	4.8	.10	0	----------
	.12	4.7	.87	.06	16
Orangeburg subsoil	0	4.8	.12	.01	----------
	.12	4.6	1.68	.04	33

[1] All treatments replicated 4 times. Soils applied at rate of 50 g of colloid per pot.

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TABLE 24.—*Effects of different soils on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate calculated from weight of crop	Quantity of P_2O_5 applied recovered in crop	Efficiency of superphosphate calculated from P_2O_5 in crop
	Gram		*Grams*	*Gram*	*Percent*	*Gram*	*Percent*
None	0	6.0	0.31	0.07	----------	0	----------
	.025	5.9	1.92	.14	100	.00774	100
	.050	5.4	3.32	.31	100	.01637	100
	.100	5.4	4.60	.17	100	.03406	100
Carrington soil	0	4.8	.35	.03	----------	----------	----------
	.050	4.8	1.98	.15	51	.00779	50
Carrington subsoil	0	5.4	.20	.01	----------	----------	----------
	.050	5.0	2.54	.12	76	.01235	78
Clarksville soil	0	4.8	.27	.02	----------	----------	----------
	.050	4.8	2.27	.18	64	.01111	73
Clarksville subsoil	0	5.5	.10	0	----------	----------	----------
	.050	5.0	.52	.03	13	.00151	10
Manor soil	0	4.7	.26	.01	----------	----------	----------
	.050	4.7	2.09	.12	58	.00959	60
Manor subsoil	0	5.4	.08	0	----------	----------	----------
	.050	5.3	.75	.05	21	.00293	20
Miami soil	0	5.3	.25	.02	----------	----------	----------
	.050	5.2	2.23	.17	63	.01152	73
Miami subsoil	0	7.9	.11	0	----------	----------	----------
	.050	7.9	1.33	.03	38	.00570	38

[1] All treatments replicated 4 times; soils applied at rate of 50 g of colloid per pot.

TABLE 25.—*Effects of different soils on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot, of plants above-ground	Probable error of the average	Efficiency of superphosphate calculated from weight of crop	Quantity of P_2O_5 applied recovered in crop	Efficiency of superphosphate calculated from P_2O_5 in crop
	Gram		*Grams*	*Gram*	*Percent*	*Gram*	*Percent*
None	0	5.7	0.15	0.01	----------	----------	----------
	.025	----------	1.73	.12	100	0.00639	100
	.050	----------	2.79	.14	100	.01091	100
	.100	4.8	4.06	.11	100	.03520	100
Chester soil	0	----------	.32	.02	----------	----------	----------
	.050	5.6	1.26	.06	30	.00480	38
Chester subsoil	0	----------	.06	0	----------	----------	----------
	.050	4.7	.13	0	2	----------	----------
Hagerstown soil	0	----------	.10	0	----------	----------	----------
	.050	6.7	.43	.01	11	----------	----------
Hagerstown subsoil	0	----------	.08	0	----------	----------	----------
	.050	6.6	.38	.02	10	----------	----------
Sharkey soil	0	5.0	.74	.06	----------	----------	----------
	.050	4.8	4.38	.12	159	.02229	148
Stockton soil	0	6.9	.64	.02	----------	----------	----------
	.050	6.7	4.37	.10	186	.02222	146
Stockton subsoil	0	8.1	1.39	.05	----------	----------	----------
	.050	8.1	4.08	.05	105	.01878	130

[1] All treatments replicated 4 times; soils applied at rate of 50 g of colloid per pot.

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TABLE 26.—*Effects of different soils on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot, of plants above-ground	Probable error of average	Efficiency of superphosphate
	Gram		*Grams*	*Gram*	*Percent*
None	0	5.6	0.10	0	
	.025	5.2	.39	.03	100
	.100	4.5	1.09	.12	100
Wabash soil	0	4.7	.41	.01	
	.050	4.7	1.39	.08	198
Wabash subsoil	0	4.9	.21	.01	
	.050	4.6	1.08	.02	175
Cecil soil	0	5.5	.08	0	
	.050	4.9	.16	.01	14

[1] All treatments replicated 4 times; soil added at rate of 50 g of colloid per pot.

TABLE 27.—*Effects of different soils on the efficiency of superphosphate in quartz sand* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Average oven-dry yield per pot, of plants above-ground	Probable error of average	Efficiency of superphosphate
	Gram		*Grams*	*Gram*	*Percent*
None	0	5.7	0.09	0	
	.025		1.50	.11	100
	.050	4.6	3.12	.08	100
	.100		4.02	.10	100
Carrington soil	0		.12		
	.050	4.8	1.78	.10	58
Hagerstown soil	0		.09		
	.050	6.9	.36	.01	10
Hagerstown subsoil	0		.08		
	.050	6.8	.22	.01	6
Huntington subsoil	0		.08		
	.050	6.2	.19	.02	4
Manor soil	0	4.8	.08		
	.050	4.9	1.16	.08	40
Marshall soil	0		1.67		
	.050	5.0	5.08	.12	142
Marshall subsoil	0	6.2	.09		
	.050	5.6	1.57	.03	52
Miami soil	0		.11		
	.050	4.8	1.47	.09	48
Miami subsoil	0		.08		
	.050	7.8	.56	.01	18
Norfolk soil	0		.10		
	.050	5.2	.29	.02	6
Norfolk subsoil	0		.07		
	.050	4.6	.09	0	1
Orangeburg soil	0	4.5	.32		
	.050	4.4	2.27	.20	66
Orangeburg subsoil	0		.08		
	.050	4.8	.11	.10	1
Sassafras subsoil	0		.28		
	.050	6.3	.75	.06	16

[1] No-phosphate treatments not replicated; other treatments replicated 5 times. Soils applied at rate of 50 g of colloid per pot.

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TABLE 28.—*Influence of hydrogen-ion concentration on the extent that soil additions lower the efficiency of superphosphate* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	$NaHCO_3$ added per pot	pH of medium after growth	Oven-dry yield, per pot, of plants aboveground			Efficiency of superphosphate
				Series A	Series B	Average	
	Gram	*Gram*		*Grams*	*Grams*	*Grams*	*Percent*
None	0	0	6.2	0.12	0.12	0.12	----------
	.05	0	4.2	2.90	2.37	2.64	100
	.10	0	4.2	3.66	3.16	3.41	100
	0	.4	8.0	.08	.07	.08	----------
	.05	.4	5.0	2.03	1.77	1.90	72
Cecil soil	0	0	6.1	.09	.09	.09	----------
	.05	0	5.0	.96	.84	.90	32
	0	.6	6.3	.11	.09	.10	----------
	.05	.6	6.3	.92	.95	.94	33
Cecil subsoil	0	0	5.6	.08	.08	.08	----------
	.05	0	4.5	.84	.53	.69	24
	0	.6	8.0	.07	.07	.07	----------
	.05	.6	8.2	.32	.45	.39	13
Clarksville soil	0	0	5.5	.16	.18	.17	----------
	.05	0	5.3	1.77	2.45	2.11	77
	0	.6	6.3	.10	.10	.10	----------
	.05	.6	6.3	.61	.97	.79	27
Clarksville subsoil	0	0	5.3	.07	.07	.07	----------
	.05	0	4.8	.54	.55	.55	19
	0	.6	6.9	.06	.05	.06	----------
	.05	.6	6.9	.23	.28	.26	8
Sassafras soil	0	0	5.3	.15	.18	.17	----------
	.05	0	4.7	1.44	1.45	1.45	51
	0	.6	6.5	.11	.12	.12	----------
	.05	.6	6.3	.58	.79	.69	22

[1] Each treatment replicated 2 times; soils added at rate of 50 g of colloid per pot.

TABLE 29.—*Influence of hydrogen-ion concentration on the extent that soil additions lower the efficiency of superphosphate* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	Base fertilizer	$NaHCO_3$ added per pot	pH of medium after growth	Average oven-dry yield, per pot, of plants aboveground	Probable error of the average	Efficiency of superphosphate
	Gram		*Gram*		*Grams*	*Gram*	*Percent*
None	0	No. 2, standard	0	6.6	0.06	----------	----------
	.05	do	0	3.9	2.74	0.12	100
	.10	do	0	----------	3.45	.04	100
Cecil soil	0	No. 2, standard	0	----------	.09	----------	----------
	.05	do	0	5.2	1.06	.07	37
	0	do	.6	----------	.10	----------	----------
	.05	do	.6	6.2	.88	.05	33
	0	No. 7, all nitrate	0	6.6	.06	----------	----------
	.05	do	0	6.6	.49	.08	16
	0	do	.4	----------	.08	----------	----------
	.05	do	.4	7.1	.67	.01	22
Cecil subsoil	0	No. 2, standard	0	----------	.06	----------	----------
	.05	do	0	5.7	.36	.04	11
	0	do	.4	----------	.07	----------	----------
	.05	do	.4	7.2	.19	.02	4
	0	do	.6	----------	.06	----------	----------
	.05	do	.6	7.8	.14	.01	2
Clarksville soil	0	No. 2, standard	0	----------	.09	----------	----------
	.05	do	0	4.6	1.91	.04	68
	0	do	.6	----------	.06	----------	----------
	.05	do	.6	6.6	1.20	.07	44
	0	No. 7, all nitrate	.4	----------	.07	----------	----------
	.05	do	.4	7.7	1.05	.03	38
Clarksville subsoil	0	No. 2, standard	0	----------	.05	----------	----------
	.05	do	0	5.4	.41	.03	14
	0	do	.6	----------	.06	----------	----------
	.05	do	.6	6.8	.15	0	2
	0	No. 7, all nitrate	.4	----------	.06	----------	----------
	.05	do	.4	6.8	.23	.01	7
Sassafras soil	0	No. 2, standard	0	----------	.17	----------	----------
	.05	do	0	4.4	2.77	.02	98
	0	do	.6	----------	.10	----------	----------
	.05	do	.6	5.6	1.03	.04	35
	0	No. 7, all nitrate	.4	----------	.12	----------	----------
	.05	do	.4	6.9	1.51	.11	52

[1] No-phosphate treatments not replicated; other treatments replicated 3 times. Soils added at rate of 50 g of colloid per pot.

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TABLE 30.—*Effects of activated charcoal and peat on the efficiencies of superphosphate and raw rock phosphate in quartz sand* [1]

Kind of colloid or peat mixed with quartz sand	P_2O_5 applied per pot and source superphosphate or raw rock phosphate	pH of medium after growth	Average oven-dry yield, per pot of plants above-ground	Probable error of the average	Efficiency of phosphate calculated from weight of crop	Quantity of P_2O_5 applied recovered in the crop	Efficiency of phosphate calculated from P_2O_5 in crop
	Gram		*Grams*	*Gram*	*Percent*	*Gram*	*Percent*
None	0	5.6	0.15	0.01			
	0.025 super [2]	4.8	.87	.01	100	0.00597	100
	0.050 rock [3]	4.5	1.65	.17	100	.01090	100
	0.100 rock [3]	4.5	2.37	.09	100	.02448	100
	0.200 rock [3]	4.8	1.09	.03	16	.01036	24
Charcoal of pH 4.3	0	6.3	.19	.01			
	0.050 super [2]	4.5	2.42	0	200	.01983	166
	0.200 rock [3]	5.0	1.28	.04	19	.01219	28
Charcoal of pH 9.6	0	6.4	.24	.01			
	0.050 super [2]	5.3	2.11	.07	153	.01533	132
	0.200 rock [3]	6.3	.66	.02	7	.00486	10
Peat of pH 5.8	0	5.6	.80	.03			
	0.050 super [2]	5.6	3.08	.04	215	.02521	206
	0.200 rock [3]	5.4	2.34	.03	27	.01672	36
Peat of pH 3.5	0	4.2	.71	.10			
	0.050 super [2]	4.2	1.46	.12	52	.00788	68
	0.200 rock [3]	4.2	1.48	.06	14	.01679	36

[1] Treatments with peat of pH 5.8 duplicated; treatments with peat of pH 3.5 and with charcoal triplicated; controls in quartz sand alone replicated 4 times. Charcoals and peats added at rate of 10 g per pot.
[2] Superphosphate.
[3] Rock phosphate.

TABLE 31.—*Effects of activated charcoal of pH 4.1 on the efficiency of superphosphate in quartz sand and quartz-sand-soil mixtures* [1]

Kind of soil mixed with quartz sand	P_2O_5 applied per pot	pH of medium after growth	Charcoal of pH 4.1 added per pot	Average oven-dry yield per pot of plants above-ground	Probable error of average	Efficiency of superphosphate, calculated from dry weight	Quantity of P_2O_5 applied recovered in the crop	Efficiency of superphosphate, calculated from P_2O_5 in crop
	Gram		*Grams*	*Grams*	*Gram*	*Percent*	*Gram*	*Percent*
None	0	6.6	0	0.06	0			
	.025		0	.93	.08	100	0.00465	100
	.050	4.2	0	2.86	.04	100	.01783	100
	.100		0	3.88	.06	100	.04094	100
Clarksville soil	0		10	.10	0			
	.050	4.2	10	4.65	.12	200+	.02484	130
	0		0	.08	0			
	.050	4.6	0	1.48	.06	64	.00818	64
	0		10	.12	0			
	.050	4.7	10	2.95	.03	100	.01267	80
Clarksville subsoil	0		0	.07	0			
	.050	5.3	0	.28	.01	12	.00078	10
	0		10	.08	0			
	.050	4.8	10	.54	.03	27	.00188	22
Cecil subsoil	0		0	.07	0			
	.050	4.6	0	.38	.03	18	.00131	16
	0		10	.08	0			
	.050	4.5	10	.79	.07	42	.00264	30

[1] No-phosphate treatments replicated 3 times; other treatments 4 times; soils added at rate of 50 g of colloid per pot.

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Technical Bulletin No. 372 August 1933

A CLASSIFICATION OF NORTH AMERICAN AGALLIAN LEAF HOPPERS

BY

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Bureau of Entomology

United States Department of Agriculture, Washington, D.C.

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TECHNICAL BULLETIN No. 372 August 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

A CLASSIFICATION OF NORTH AMERICAN AGALLIAN LEAF HOPPERS[1]

By P. W. OMAN, *junior entomologist, Division of Taxonomy of Insects, Bureau of Entomology*

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INTRODUCTION

The only previous study of all the North American species of the genus *Agallia* was that made by Osborn and Ball in 1898 (*28*),[2] in which 12 species were treated. Since that time various species have been described by Uhler, Baker, Ball, Osborn, Van Duzee, Olsen, and DeLong and Wolcott, and some of the described species have been synonymyzed. Because of the considerable number of species involved, their great similarity, the lack of published illustrations, and, in many cases, inadequate descriptions, identification of species has been very uncertain. Problems in insect interrelationship, requiring the accurate identification of species in this group, have made necessary an attempt at a revisional study of the classification of these insects, and the present bulletin is an outgrowth of such investigations.

Since the writer has had little opportunity for personal field observations, he has necessarily relied on other workers for most of the

[1] The preparation of this bulletin has been greatly facilitated by the assistance rendered by many entomological workers and institutions, without which many of the more difficult problems could not have been solved. The writer is particularly indebted to H. G. Barber, of the Bureau of Entomology, E. D. Ball, of the University of Arizona, and P. B. Lawson and R. H. Beamer, of the University of Kansas, for much constructive criticism and many helpful suggestions. The studies here presented have been based on several thousand specimens in the U.S. National Museum collection; on more than 5,000 specimens furnished by the Entomological Museum of the University of Kansas through Hungerford and Beamer; on valuable material and host-plant data supplied by E. D. Ball, of the University of Arizona, and E. W. Davis, of the sugar-beet leaf-hopper laboratory at Salt Lake City; and on specimens lent for study by D. M. DeLong, of Ohio State University, Herbert Osborn, of the Ohio Biological Survey, H. L. Dozier and Sam C. McCampbell, of Colorado State College, C. E. Olsen, of the American Museum of Natural History, D. A. Wilbur, of Kansas State College of Agriculture and Applied Sciences, and Harold Morrison and H. G. Barber, of the Bureau of Entomology. Type examples of various species have been received for study from E. D. Ball, D. M. DeLong, Herbert Osborn, and C. E. Olsen, of the above-named institutions, and from E. P. Van Duzee, of the California Academy of Sciences, and C. J. Drake, of Iowa State College. To all these the writer expresses his sincere thanks.

[2] Italic numbers in parentheses refer to Literature Cited, p. 71.

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records concerning host plants and habitats. The status of some of the forms treated remains in doubt, but it is hoped that the study may be continued and these points decided when more thorough and careful observations are made.

HISTORY

The genus *Agallia* was erected by Curtis in 1833 (*11*) to accommodate his *consobrina*. Scott in 1874 (*32*) placed *consobrina* Curt. as a synonym of *puncticeps* Germ., this being the present status of that species. The chief characters of the original description are as follows:

> Rather short and ovate, face ovate-trigonate,—head from above forming a very narrow lunule, ocelli 2 in the forehead,—thorax narrower than the head, transverse-ovate.

Osborn and Ball (*28*), in their monograph of the North American species, pointed out the existence of three distinct groups within the genus, designating them as groups I, II, and III. Kirkaldy in 1907 (*18, p. 11, 30–31*) gave these groups generic rank and applied to them the names *Agallia*, *Agalliopsis*, and *Aceratagallia*, with *consobrina* Curt., *novella* Say, and *sanguinolenta* Prov., respectively, as types. Van Duzee (*43*) considered these groups as subgenera in the genus *Agallia*, but Lawson (*22, p. 55–58*) again gave them generic ranking. Because of the very distinct and constant differences existing between these groups, the writer also has deemed it advisable to treat them as distinct genera, rather than to place them under a single name and thus indicate a very close relationship that does not exist. As a result of these studies it has been necessary to describe a fourth, new genus to accommodate species that evidently do not come within the limits of those already established.

RELATIONSHIPS

The genus *Agallia* and related genera belong in the subfamily Bythoscopinae, which is distinguished from other subfamilies of the Cicadellidae by the position of the ocelli, which are always present on the front, below the vertex rather than on the disk of the vertex or the vertex margin, and by the character of the head, which has no distinct margin or carina between the vertex and the front. The genera treated in this bulletin may be separated from other North American genera of the Bythoscopinae by the following key:

1 Form broad, rather depressed, front somewhat swollen; antennal pits with a distinct overhanging ledge which is transverse or nearly so. Elytra usually clothed with short setae *Bythoscopus* and *Straganiopsis*.
Form neither broad nor depressed, or, if so, then antennal pits without overhanging ledge. Ledge, when present, not transverse but distinctly oblique. Elytra not clothed with short setae 2

2 (1) Distance between ocelli distinctly greater than twice the distance from ocellus to eye; antennal pits deep; elytra broad, apical cells short *Macropsis* and *Oncopsis*.
Distance between ocelli not over twice the distance from ocellus to eye; antennal pits shallow 3

3 (1) Elytra with distinct appendices; head, including eyes, distinctly wider than body ..... *Idiocerus*.
Elytra without distinct appendices; head not so distinctly wider than body .... *Agalliopsis*, *Agallia*, *Aceratagallia*, and *Agalliana*.
These genera are differentiated on page 7.

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All species of these genera are characterized by the robust form, short, broad vertex, shallow antennal pits, and the absence of appendices in the elytra. Osborn and Ball distinguished their three groups by differences in the shape of the posterior margin of the vertex, the character of the surface of the pronotum, the form of the vertex of the nymphs, and the wing venation. Lawson (*21, p. 48–50*) confirmed the correctness of this basis for segregation when he pointed out the differences in the internal male genitalia. The new genus herein described is distinguished by a combination of the above-mentioned characters.

ECONOMIC IMPORTANCE OF THE GROUP

Until DeLong and Davidson (*12*) discussed the common species attacking economic crops in the United States, *sanguinolenta* was the only species of the *Agallia* group to attract enough attention as a pest to receive more than an occasional brief reference to its economic importance. It is therefore safe to state that the damage done by the various species of the group has been greatly underestimated or overlooked. This, probably, is due chiefly to two things, the tendency to overlook the injury, and the habit of attributing injury, when observed, to *sanguinolenta*. These leaf hoppers are frequently overlooked entirely because of their dull colors and secretive habits, and the poor condition of a crop may be attributed to drought when in reality the plants have been weakened by the great numbers of tiny leaf hoppers sucking their sap.

Although the group is usually considered as one feeding primarily upon cereal, forage, and truck crops, Ball states that he has found that most of the species, under normal conditions, have as hosts a distinct plant or group of plants, from which they seldom stray. Thus most of the species become pests of economic crops only when their normal hosts are not available, as is often the case in extensively cultivated regions. As Ball (*5, p. 50–51*), Osborn (*23, p. 15*), Gibson (*16*), DeLong and Davidson (*12, p. 377*), and others have pointed out, the principal crops affected are clover, alfalfa, soybeans, and beets, as well as meadow and pasture lands.

DeLong and Davidson (*12*) treated 11 species in their paper, namely, *sanguinolenta*, *cinerea*, *uhleri*, *californica*, *lyrata*, *bigeloviae*, *gillettei*, *quadripunctata*, *constricta*, *deleta*, and *novella*, all as members of the genus *Agallia*. In this bulletin, inasmuch as the taxonomic treatment has been on the basis of genera rather than of subgenera, it seems best to consider the economic species in the same way.

The genus *Agalliopsis* is of relatively little importance, since only a single species, *novella*, occurs so commonly as to do damage, and then only in the eastern half of the United States and south into Texas. Van Duzee's *novella* var. *tropicalis*, described from Jamaica, but known to occur in Central America as well, is also fairly abundant and may be expected to cause injury to cultivated crops.

In the genus *Agallia* the best-known injurious species are *constricta* and *quadripunctata*. Of the two, *constricta* is the more common on economic crops and probably of considerably more importance. Its normal habitat is distinctly the southeastern part of the United States, as it is not found commonly west of eastern Kansas, Nebraska, and Texas, or north of the southern half of Pennsylvania, Ohio, and

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Indiana. On the other hand, *quadripunctata* is found most abundantly in the northeastern part of the United States and eastern Canada, overlapping the northern limits of *constricta* in its southern distribution. It occasionally occurs, however, as far west as Colorado, Utah, Idaho, California, and Oregon in situations comparable to those of eastern Canada, but not in sufficient numbers to be of importance. *A. deleta*, found in Florida, South Carolina, Georgia, Virginia, Massachusetts, New Jersey, and New York, and included by DeLong and Davidson as an injurious species, is of extremely doubtful importance. *A. albidula* is a common pest of truck crops throughout the Antilles and probably assumes economic importance in South America also, since it is likewise abundant there. Among the crops reported as being injured by this common form are melon, asparagus, bean (*Phaseolus vulgaris*), and tomato. Little is known concerning *repleta* in Trinidad and Central America, or *modesta* and *lingula* in Central America, but these two species were taken in great numbers in that region by Harold Morrison, mostly by sweeping grasses, and cannot be ignored as potential pests of cultivated crops. In addition, both species occur in Mexico, and *lingula* is found in southern Texas.

It is in the genus *Aceratagallia* that the largest number of economic species occur, and also the species of greatest economic importance, at least in the United States. As a result of this study of the genus, 8 species, all from continental North America and 5 of them considered as new, have been definitely associated with economic crops, while 7 others are placed as possible, though doubtful, pests. The most common, of course, is *sanguinolenta*, found in large numbers on various crops in the eastern portion of the United States but much less abundantly west of eastern Kansas, and of questionable importance in that region. The writer has found this common species, in both nymph and adult stages, literally teeming on a pure stand of Japanese clover (*Lespedeza striata*) in the vicinity of Washington, D.C. In view of the fact that this is now a common and valuable forage crop as far west as eastern Kansas, the annual loss in pasturage due to the feeding of this insect must be enormous. This species is also common in all stages on *Cassia chamaecrista*, another legume. Its occurrence on alfalfa, clover, and bean is well known. The writer agrees with DeLong and Davidson in doubting the authenticity of records of *sanguinolenta* from California and is inclined to believe that it does not occur farther west than Utah and Arizona. The only other species common in the eastern half of the United States are *vulgaris* and *accola*. *A. uhleri* occurs from Kansas, Texas, and Iowa west into Arizona and southern Utah. DeLong and Davidson's records of *uhleri* from California apply to *curvata*, a new species. *A. calcaris* is a pest of beets in western Kansas and eastern Colorado; it occurs also in Texas but is not recorded from cultivated crops from that State. In western Colorado, Utah, Wyoming, Montana, and Idaho between the Rocky Mountains and the Sierra Nevadas, this species is replaced by *arida*, which also occurs on beets as well as other truck crops and wild host plants. Another common species farther north in this region is *fuscoscripta*, which is found in northern Colorado, Wyoming, Montana, Idaho, Washington, and British Columbia, but apparently is not much of a crop pest. Most of Carter's references (*10, p. 54–55*) to *A. sanguinolenta* should be re-

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ferred to this species. Two distinctly western species of importance are *curvata* and *obscura*, discussed by DeLong and Davidson under the names *uhleri* and *lyrata*, respectively. *A. curvata* was taken by DeLong on numerous crops, but mostly on alfalfa, and he reports the species here called *obscura* from 22 different crops. Both of these species are common in California and southern Oregon west of the mountains. Among the species of doubtful importance are true *lyrata* and *californica*, both occurring in California and southern Oregon, typically in alpine regions but occasionally found on cultivated crops. The importance of *bigeloviae*, *gillettei*, *inconspicua*, *cinerea*, *dondia*, *abrupta*, *vastitatis*, and others from the arid western and southwestern regions is as yet unknown, but the indications are that some of them will become pests as areas of cultivation are extended.

Agalliana sticticollis (Stål) has essentially the same distribution as *Agallia albidula* Uhl. and is of about the same importance as a pest of crops in the Antilles. DeLong and Wolcott (*45, p. 258–259*) reported it on carrots in Puerto Rico and applied the name *carrotovora*, and Osborn (*27, p. 91*) has reported it from sweetpotato. Fawcett (*13, 14*), Henderson (*17*), Severin and Henderson (*33*), and others have reported *A. sticticollis* (Fawcett (*13*) as *sanguinolenta*) as a transmitter of curly top of beets in the Argentine, but the writer believes that these references all apply to a distinct species, closely related to *sticticollis*. These investigations, however, would seem to indicate that *sticticollis* must be considered as a potential carrier of virus diseases.

CHARACTERS USED IN THE CLASSIFICATION

Since the external morphology of the Cicadellidae has been discussed adequately by several workers (*20, p. 11–15; 21, p. 38–43*), a brief résumé of the characters found to be of greatest diagnostic value in the genera and species here considered is believed to be sufficient for this study. The terminology in general use among workers in the group has been followed where possible, but a few additional terms have been used in referring to the characters of the internal male genitalia. These will be explained under the discussion of those characters.

In general the size and form of any species in this group have been found to be constant. Differences in size and general shape, heretofore attributed to variation, have been found in most cases to represent specific differences. The intensity of coloration is usually unreliable, but the color pattern is constant and, except in the genus *Aceratagallia*, is quite distinctive. The shape of the vertex and that of the pronotum are valuable as comparative characters, but are seldom conspicuous enough to be used in the written descriptions for species segregation. The contour and venation of the elytra are also valuable, but the best external characters for the separation of closely related species are those of the male and female genitalia, particularly the shape of the plates of the former; in fact, many of the species of *Aceratagallia* can be separated externally in no other way than by examination of these.

In a search for characters to supplement the external ones it was found that the internal male genitalia were usually, though not al-

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ways, very distinctive. It was concluded that a combination of both internal and external characters must be used for the satisfactory differentiation of many of the species.

Lawson (*21, p. 56–58*) is the only worker who has discussed and figured the internal genital characters of the males of species of the *Agallia* group. He pointed out the existence, not only of specific characters, but of characters that were significant in the three genera treated. However, his statement that each style of the male genitalia of *Agalliopsis novella* consists of two distinct sclerites is erroneous, the error probably being due to the fact that the styles are very lightly sclerotized along the median line. No specimen examined by the writer in the course of this study has had the styles consisting of two pieces. All the species of *Agalliopsis* studied have the styles forked posteriorly, much as in *Agallia*, and the two forks are here designated as the inner and outer forks, the inner one being the one that arises from the shank of the style nearer the median line of the body, usually the more heavily sclerotized of the two. The processes of the pygofer, when not merely extensions of the posterior margins, are here called pygofer hooks, while the processes of the tenth segment are called dorsal spines, following the terminology used for corresponding structures in different genera of the Eupteryginae. The best specific characters are found in the aedeagus and dorsal spines, and, to a lesser extent, in the pygofer hooks.

In the genus *Agallia* the aedeagus is the chief internal structure presenting valuable characters, although the posterior margins of the pygofer, seldom seen until the genital capsule has been cleared, also show modifications useful in classification. In the genus *Aceratagallia*, on the contrary, the aedeagus is of little value, but the posterior portion of the styles furnishes excellent characters. The styles have typically a rather truncate tip, thus forming two quite distinct angles which are designated as the inner and outer points; of the two the inner point is the more nearly ventral in position and is placed nearer the median line of the body when the styles are in their normal position. There are no pygofer hooks in this genus, and the dorsal spines are of little or no diagnostic value. In the genus *Agalliana* both the aedeagus and the dorsal spines furnish reliable characters.

The construction of satisfactory keys for the species of the genera treated has been one of the most difficult parts of this study. Because of the similarity in appearance of many of the species it has been necessary to utilize to a considerable extent genitalia characters for the segregation of these species in the keys. The task has been further complicated by the fact that some of the species are known from only a single sex and others have evident specific characters in the male sex only. The usefulness of the keys can be greatly increased by frequently consulting the illustrations, expecially those drawings referred to specifically in the keys.

TECHNIC USED IN THE STUDY

PREPARATION AND HANDLING OF THE SPECIMENS

Most workers are familiar with the essential process involved in preparing the male genitalia for study. The abdomen, or a considerable portion of the tip, is carefully removed with a sharp needle

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and treated with a potassium hydroxide solution, either by being heated gently or soaked, until the genital capsule is sufficiently cleared to allow the internal structures to be seen. Staining is not necessary in this group, because the internal structures are usually heavily enough sclerotized to be easily distinguished.

After the specimen is sufficiently cleared, it should be allowed to remain in distilled water for a time to remove the excess potassium hydroxide, and then transferred to glycerin for study. The genital capsules may be temporarily retained by placing them in a small quantity of glycerin in a tiny vial, 5 mm or less in outside diameter and not over 15 mm long, which may be attached to the pinned specimen by thrusting the pin through the cork. Since glycerin is practically nonvolatile, the capsules can be kept in this way for some time without danger of loss or mixing with others.

In studying the genitalia the use of a hollow-ground slide permits easy manipulation of the specimen. The genitalia may be handled easily with a tiny loop in the end of a no. 0 or 00 pin thrust in a wooden handle. For manipulation of the specimen under the microscope "minuten Nadeln" thrust in a wooden handle were found to be satisfactory. These needles may also be used to remove such structures as are of diagnostic value but cannot be seen sufficiently in situ.

PREPARATION OF ILLUSTRATIONS

The illustrations used are of two types—outline drawings with stippling where needed to show the color pattern, and photographic enlargements.

A micrometer disk ruled in squares and placed in the ocular of a binocular microscope and coordinate paper ruled with pale-blue lines were used to secure accurate outlines for parts that are shown in line drawings. Unless otherwise stated in the explanation of the illustrations, all external drawings are enlarged approximately 25 times, lateral views of male genitalia approximately 45 times, and detail drawings of aedeagi, styles, etc., approximately 55 times. The drawings, therefore, give an accurate idea of the relative size in the various species.

The photographic enlargements were made by J. G. Pratt, of the Bureau of Entomology; and most of the prints have been worked over with a pencil to emphazise the color patterns. Photographic illustrations are not included for all the species discussed in the bulletin, since many of them do not show sufficient contrast in color pattern to photograph satisfactorily, and others are represented only by unique types.

KEY TO THE GENERA

1 Pronotum finely granulated, neither pitted nor transversely rugulose. 2
Pronotum either pitted or transversely rugulose. 3

2 (1) Vertex distinctly shorter medially than next the eye, posterior margin elevated medially and sinuately curved laterally. *Agalliopsis*, p. 8.
Vertex of nearly uniform length throughout its width, posterior margin smoothly rounded and not distinctly elevated. *Agallia*, p. 24.

3 (1) Pronotum pitted; styles of internal male genitalia forked posteriorly *Agalliana*, p. 70.
Pronotum transversely rugulose; styles of internal male genitalia not forked posteriorly. *Aceratagallia*, p. 45.

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The genus AGALLIOPSIS Kirkaldy

Vertex very short medially, usually distinctly longer next the eyes, the hind margin sinuately curved laterally and extending some distance behind the eyes. Markings of head and pronotum usually consisting of dark spots. Pronotum with lateral margins obsolete, posterior margin often convex but usually faintly notched medially. Elytra long and slender, venation often obscure; with 4 apical and either 2 or 3 anteapical cells. Internal male genitalia with the styles forked, aedeagus often with accessory processes, tenth segment often quite distinct and bearing spines of various shapes; pygofer with hooklike processes in some species. Nymph with upward-projecting processes on the vertex.

Type of the genus, *Jassus novellus* Say.

There exist within the genus several quite distinct groups of closely related species, but none of them is now considered as deserving subgeneric rank. The most apparent group is made up of five West Indian species—namely, *ballii*, *pepino*, *conformis*, *maculata*, and *clitellaria*—all having very distinctive markings on the vertex and the pronotum. When the males of more species are available for examination, there will probably be found a distinct group in which the males have the type of genital plates peculiar to *oculata* and *peneoculata*, another group in which the male plates are of the *novella* and *variabilis* type, and a third of the type possessed by *huachucae* and *magnifica*.

Of the species in this genus, only the female sex of *clitellaria*, *scortea*, *tenella*, and *anomala* and the male sex of *conformis*, *magnifica*, *cervina*, *dubiosa*, *exilis*, *huachucae*, and *ancoralis* are known to the writer.

Key to the species of AGALLIOPSIS

1	Pronotum with discal spots each side of median line pale colored, and bordered, or partially so, with brown or fuscous, or, if not dark bordered, the elytra maculated. Veins of elytra broadly pale, at least apically, cells darker, or, if veins not pale, elytra with a broad yellow saddle. West Indian species	2
	Pronotum with discal spots dark, or, if pale colored, not bordered with brown or fuscous. Veins of elytra concolorous with, or paler than, the cells, but if paler usually narrowly so and without a distinct line of demarcation between light and dark areas	6
2 (1)	Elytra fuscous with a bright lemon-yellow elytral saddle extending from tip of scutellum two thirds the distance to apex of clavus, narrowing to costal margin *clitellaria*, p. 13.	
	Elytra not as above	3
3 (2)	Elytra maculated, with maculae arranged in rather indistinct transverse bands. Elytra with few cross veins *maculata*, p. 11.	
	Elytra not maculated, or, if appearing maculated, with numerous cross veins	4
4 (3)	Elytra with numerous cross veins *ballii*, p. 10.	
	Elytra with few cross veins	5
5 (4)	Length 3.5 mm or more; male plates bluntly subtriangular (fig. 1, B) *conformis*, p. 11.	
	Length 3 mm or less; male plates abruptly narrowed to pointed tips (fig. 1, P) *pepino*, p. 12.	
6 (1)	Length 5.25 mm or more, species large and robust *magnifica*, p. 20.	
	Length not over 5 mm; if near 5 mm in length, very slender	7

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7 (6) Veins of elytra obscure, concolorous; elytral markings, if any, consisting of a smoky, transverse band behind the middle of the clavus. Female genital segment truncate. General ground color grayish or yellowish green, not brown; markings on vertex and pronotum consisting of small spots, or sometimes with a faint median line. Subtropical 8

Veins of elytra distinct, or, if obscure and concolorous, species brown or brownish and female genital segment not truncate. Pronotal markings usually very large and heavy 9

8 (7) Elytra with a smoky, transverse band behind middle of clavus. Length 3.5 mm or less ..... *cincta*, p. 14.

Elytra without smoky, transverse band. Length 3.75 mm *scortea*, p. 13.

9 (7) Elytra deep brown with a broken transverse band of white behind middle of the clavus ..... *cervina*, p. 16.

Elytra usually light brown or gray, no transverse white vitta 10

10 (9) Pronotum with posterior margin broadly pale, remainder golden brown with narrow median line, oblique spots laterally on disk, and anterior margins laterally, fuscous. Female genital segment triangularly produced and notched at apex. Second cross vein present in elytra ..... *tenella*, p. 18.

Pronotum not as above, or if so with elytra lacking second cross vein 11

11 (10) Pronotum very pale yellowish brown, with a faint median line and small spots laterally on disk fuscous. Elytra with only cells of clavus, and corium adjacent to clavus, embrowned; costal margin broadly hyaline. Second cross vein between sectors absent or, if occasionally present, the resulting anteapical cell not over one third as long as the second anteapical cell. Female genital segment truncate or very shallowly concave. Length less than 4 mm ..... *anomala*, p. 23.

Pronotum and elytra not marked as above or, if so, with second cross vein in elytra present and resulting cell one half as long as second anteapical cell, or with female segment not as above 12

12 (11) Aedeagus of male with lateral processes at tip and base (fig. 14, K, L); pygofer hooks simple, male plates subtriangular *dubiosa*, p. 18.

Aedeagus with lateral processes only at tip or, if with basal lateral processes, pygofer hooks coarsely serrate or absent and male plates not subtriangular 13

13 (12) Aedeagus of male slender, with long lateral processes extending latero-cephalad from tip 14

Aedeagus of male without such processes 16

14 (13) Lateral processes of aedeagus forked (fig. 13, P, Q). Species long and slender, male plates subtriangular ..... *exilis*, p. 21.

Lateral processes of aedeagus not forked, species more robust, male plates either subtriangular or flat and tapering 15

15 (14) Male plates flat and tapering, lateral processes of aedeagus very slender, strongly diverging (fig. 13, M) ..... *huachucae*, p. 14.

Male plates subtriangular, lateral processes of aedeagus stouter, nearly parallel (fig. 13, O) ..... *ancoralis*, p. 21.

16 (13) Aedeagus of male with lateral basal processes extending caudad (fig. 14, C, E). Female genital segment very broad, lateral angles strongly produced and posterior margin broadly concave from lateral angles 17

Aedeagus without lateral basal processes but sometimes with a fleshy sheath basally. Female genital segment narrow or, if at all broad, not concave 18

17 (16) Posterior margin of female genital segment smoothly concavely excavated ..... *novella*, p. 23.

Excavated portion of female segment with a tooth on each side, males usually dark ..... var. *tropicalis*, p. 24.

18 (16) Tip of aedeagus with forks resembling a pair of outside calipers (fig. 14, O). Female genital segment triangularly produced *brunnea*, p. 19.

Aedeagus, if forked, with forks diverging, not caliperlike. Female genital segment not triangularly produced 19

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19 (18) Aedeagus not bifid at tip, although sometimes bilobed. Posterior margin of female genital segment truncate or very slightly concave, not produced or lobed 20
Aedeagus bifid at tip, forks diverging. Posterior margin of female genital segment produced and obscurely 3-lobed ... *oculata*, p. 17.
20 (19) Second cross vein between sectors of elytra present ... *variabilis*, p. 22.
Second cross vein between sectors of elytra absent 21
21 (20) Species brownish with a transverse smoky band behind the middle of the clavus ..... *peneoculata*, p. 17.
Species gray, without transverse smoky band on elytra 22
22 (21) Spots on vertex above ocelli extending to posterior margin of vertex. Length 3.5–4 mm ..... *fuscosignata*, p. 15.
Spots on vertex above ocelli not extending to posterior margin of vertex. Length 3–3.25 mm ..... var. *minor*, p. 16.

AGALLIOPSIS BALLII (Baker)

(Fig. 1, E, F, G; fig. 13, G; pl. 1, A)

Described as *Agallia reticulata* by Ball (*4, p. 127*) in 1900 (nec. Herrick-Schaeffer, 1853). Baker (*3, p. 152*) suggested the name *ballii* to take the place of the preoccupied *reticulata*. Strikingly distinct because of the reticulate venation and peculiar color. Length of male 3–3.25 mm, of female 3.5–3.75 mm.

Color.—Face creamy, antennal pits fuscous, frons and vertex below tinged with brownish yellow. Vertex with an oblique fuscous line at the inner margin of each eye, and on the posterior margin on each side a crooked fuscous line in the shape of an interrogation mark, the base of this joining the oblique line next the eye. Ground color of pronotum bluish white; olive-brown to brown markings partly margined with fuscous in the form of a broad anterior margin laterally, a narrow median line, and a large pyriform spot on each side posteriorly, the lateral spots connected anteriorly with the anterior brown margin. Scutellum yellowish, basal angles faintly brown to fuscous. Elytra with cells bluish brown to light fuscous, veins broadly bluish white; the extra veinlets in the elytra tending to give them a mottled appearance; tips of elytra brownish. Hind wings smoky, veins darker. Males usually distinctly darker than females.

Structure.—Broad, wedge shaped, rather depressed. Vertex distinctly shorter medially than next the eyes, hind margin sinuate and extending behind the eyes laterally. Pronotum long, scarcely humped in lateral view. Elytra long, with a few extra veinlets, especially in the clavus. Costal margins of elytra broadly rounded.

External genitalia.—Last ventral segment of female about 1½ times as long as preceding segment, lateral angles broadly rounded, posterior margin broadly, angularly excavated one fourth the distance to the base. Male valve rather large, median length equal to one half the width of the posterior margin. Posterior and anterior margins parallel, lateral margins oblique. Plates rather small, together forming almost an equilateral triangle, lateral margins slightly convex. Pygofer visible laterally on each side of plates.

Internal male genitalia.—Aedeagus curved upward, tip with a tiny flangelike process dorsally and laterally. Forks of style long, inner fork exceeding outer and with apex obliquely truncate. Anal tube collar bearing a pair of spines on each side, the posterior ones longer and bent abruptly inward.

The peculiar color and color pattern, together with the broad, somewhat flattened form, will distinguish this species from other known forms.

Described from Haiti. Cotypes in collections of E. D. Ball and United States National Museum (catalog no. 43974). There are specimens at hand from Port-au-Prince, Hinche, Bayent, and Mount Puilsboreau, Haiti, collected by H. L. Dozier, and from Duarte, Santo Domingo, Dominican Republic, collected by Harold Morrison.

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AGALLIOPSIS CONFORMIS n. sp.

(Fig. 1, A, B; fig. 13, K; pl. 1, B)

Brown, with veins of elytra broadly bluish white and with black to fuscous markings on the head and thorax. Aspect of a large, pale *ballii*, but without reticulate venation. Length of male 3.75 mm.

Color.—General ground color light brown, vertex and anterior margin of pronotum golden brown. Face light brown with fuscous marks as follows: Frontal sutures, antennal pits, ring around each ocellus, spots above antennal pits, and inverted Y on vertex fuscous. Vertex with a black spot dorsally next each eye and a portion of posterior margin over each ocellus fuscous. Base of inverted Y on vertex extending to posterior margin of vertex, widened dorsally. Pronotum with a small, median, elongate, longitudinal fuscous spot anteriorly and a similar elongate transverse fuscous spot on each side just back of this; anterior margin sometimes fuscous in lateral depressed area; posterior two thirds with a large, light brown, elongate median spot and a similar irregular round spot on each side, partially margined with fuscous; a creamy-yellow stripe extending in an anteromedian direction from the hind margin of the pronotum nearly through the outer edge of each lateral spot. Scutellum yellowish brown with black basal triangles; the median circular depressions and transverse suture fuscous. Elytra brown, subhyaline, veins broadly dirty white margined with fuscous dorsally. Hind wings smoky black, veins darker.

Structure.—Wedge shaped, more depressed than *A. oculata*. Vertex slightly longer next the eyes than medially, hind margin sinuate but extending only very slightly behind the eyes laterally. Pronotum long, hind margin slightly concave, lateral margins obsolete. Elytra long, narrow, second cross vein between sectors absent. Outer claval vein forked at tip, forks joining inner claval vein and commissural line, making a rough circle dorsally.

External genitalia.—Male valve short, broad, hind margin convex. Plates short, together triangular, lateral margins slightly convex, tips pointed, equaling pygofer in length. Pygofer but little wider than plates.

Internal male genitalia.—Aedeagus rather stout and curved. Dorsal spine of tenth segment forked, ventral fork much longer than dorsal. Inner process of style nearly straight, extending far beyond outer process.

Easily distinguished from *ballii* by the lack of reticulation in the elytra and by the male genitalia, as well as the greater size.

Holotype male from Blanton mine, north of San Cristobal, Dominican Republic, July 27, 1917, Harold Morrison (377). Paratype male from San Pedro Macoris, Dominican Republic, July 15, 1917, Harold Morrison (336). Types in the United States National Museum (catalog no. 43975).

AGALLIOPSIS MACULATA (Osborn)

(Fig. 1, R, S)

Described as an *Agallia* by Osborn (*26, p. 339*) in 1926. Intermediate in character between *ballii* Baker and *pepino* DeLong and Wolcott. Length 3 mm.

Color.—General ground color light gray. Face pale, frontal sutures and lateral margins of frons faintly fuscous marked, antennal pits dark. Inverted Y on vertex and tiny arc next the inner margin of each ocellus brownish fuscous. Vertex with fuscous marks as follows: A short, median line, a short obliquely transverse line each side of this, a tiny spot above each ocellus and below the margin of the vertex, a similar spot behind each of these on the posterior margin of the vertex, and a slightly larger elongate spot next each eye. Pronotum with a very faint median line, a pair of small fuscous spots each side of this anteriorly, and a pair of larger brownish spots caudad and laterad of these. Scutellum with depressed pits and transverse suture dark. Elytra grayish subhyaline with brownish-fuscous spots arranged, dorsally at least, in rather indistinct transverse bands, 1 even with the apex of the scutellum, 1 each side of the middle of the clavus, and 1 at the apex of the clavus; the posterior 2 broader. Beyond tip of

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clavus the maculae are restricted to the cells. Veins basally intermittently gray, apically solid whitish.

Structure.—Form of *ballii* but smaller, vertex proportionately longer than in most species of *Agalliopsis*, strongly curved and with the hind margin faintly sinuate laterally. Pronotum rather elongate, lateral margins obsolete, posterior margin truncate. Elytra elongate, slightly tapering, venation indistinct basally, second cross vein between sectors present. The maculae of the elytra give the appearance of reticulate venation, although this is not the case.

External genitalia.—No female specimens have been examined by the writer, but the original description of the species gives "last ventral segment short, scarcely longer than preceding, truncate." Male valve short, transverse, lateral margins oblique, posterior margin parallel to anterior. Plates small, almost triangular, lateral margins slightly convex.

This species closely resembles pale specimens of *pepino* in the pronotal markings, but the maculated elytra will distinguish it from that species and the venation will separate it from *ballii*.

Osborn's specimens, upon which the original description was based, were from Herradura, Cuba, taken on longleaf Cuban pine, which, as he suggests, is probably the normal host. At present, the species is known from no other locality. Male allotype examined through the courtesy of Professor Osborn, in whose collection the types are deposited.

AGALLIOPSIS PEPINO (DeLong and Wolcott)

(Fig. 1, N, O, P; fig. 13, J; pl.1, C)

Described as an *Agallia* by DeLong and Wolcott (Wolcott *45, p. 258*) in 1923. A small bluish-gray species marked with black on the vertex, and brown and fuscous on the pronotum. Length 2.5–3 mm.

Color.—General ground color light bluish gray. Front embrowned, with fuscous to black marks as follows: Frontal sutures, antennal pits, and inner margins of lora, inverted Y on vertex, rings around, or semicircles below, ocelli, and spots next the eyes on level with ocelli. Anterior margin of vertex with piceous marks as follows: A small median spot, a spot above each ocellus, and one next each eye. Anterior margin of pronotum black, sometimes only laterally. Pronotum with a narrow median fuscous line and two small fuscous spots on each side anteriorly. A large, irregularly pyriform area of yellowish gray margined with fuscous on each side posteriorly, and an indistinct brown spot near each posterior lateral angle. Scutellum with black triangular spots at basal angles, small round black spots centrally, and a dark median transverse suture. Elytra brownish with bluish-white veins; a bluish-white semicircle on the inner margin of each elytron slightly behind the midpoint of the clavus, these together forming a rough circle dorsally.

Structure.—Vertex longer next the eyes than medially, extending somewhat behind the eyes and with posterior margin slightly sinuate laterally. Elytra greatly exceeding abdomen, second cross vein present or absent.

External genitalia.—Last ventral segment of female about twice as long as preceding segment, lateral angles slightly produced and rounding, hind margin roundly excavated medially. Male valve short and transverse. Plates broad basally, narrowing sharply on basal one third, then together slender and tapering to a pointed apex, slightly exceeding pygofer. Pygofer in lateral view with posterior margins produced caudally into footlike protuberances.

Internal male genitalia.—Aedeagus heavy, ventral process in lateral view with tip obliquely truncate and with two short hooks ventrally.

This species may be easily distinquished from all others by the size and distinctive color pattern of the vertex and pronotum.

Described from Puerto Rico. There are specimens at hand from various localities in Puerto Rico, Dominican Republic, Haiti, Cuba and the Virgin Islands. Types in the collection of D. M. DeLong.

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AGALLIOPSIS CLITELLARIA (Ball)

(Fig. 1, C, D)

Described by Ball (*4, p. 127*) as *Agallia clitellaria* in 1900. A striking, fuscous species with a wide saddle of bright yellow across the elytra. Length of female 2.75 mm.

Color.—Face black, with numerous testaceous spots, the most striking being an oval pair laterally and below ocelli, an oval pair above these on vertex, next the eyes, and the irregular testaceous median portion of vertex divided by a narrow longitudinal fuscous stripe which ends in a round spot at the apex of the vertex. The posterior margin of the vertex laterally is also testaceous. Ground color of pronotum dirty yellow with the following fuscous marks: The anterior margin, median line, small oval spots on each side anteriorly and large spots on each side posteriorly, the latter with the centers dirty testaceous. Scutellum fuscous except apex and a spot midway on each side, bright yellow. Elytra fuscous with a bright yellow saddle which extends from the tip of the scutellum two thirds the distance to the apex of the clavus along the commisural line, gradually narrowing laterally and extending nearly to the costal margin. Veins mostly obscure but occasionally marked with yellow.

Structure.—Vertex distinctly shorter medially than next the eye, posterior margin extending behind eyes laterally. Pronotum with lateral margins obsolete, posterior margin slightly concave. Elytra extending well beyond abdomen. The tips of the elytra of the type are damaged, but there is evidence of a second cross vein between the sectors of one elytron.

External genitalia.—Last ventral segment of female one half longer than preceding segment, posterior margin very shallowly and broadly concave, faintly notched medially.

This species is known only from the unique female type from Port-au-Prince, Haiti, but the color pattern is so striking that there can be no doubt concerning the distinctness of this species. The type, which is in the collection of E. D. Ball, has been examined through his courtesy.

AGALLIOPSIS SCORTEA (Van Duzee)

(Fig. 1, Q)

Described by Van Duzee (*41, p. 56*) in 1907 as *Agallia scortea.* Pale yellowish green with tiny fuscous spots on vertex, pronotum, and scutellum. Length 3.75 mm.

Color.—General ground color pale yellowish green with a slight tinge of olive. Face pale, with piceous to black marks as follows: Antennal pits, spots at the inner margins of the ocelli, and sutures between frons and genae, faint spots above the ocelli and larger spots next the eyes. Pronotum with the following fuscous marks: Very fine median line anteriorly, a pair of small round spots near anterior margin, and a larger, indistinct pair caudad and laterad of these. Anterior margin of pronotum laterally with traces of fuscous. Scutellum with tiny black basal triangles, the transverse suture and a pair of small spots in front of this also black. Elytra pale greenish subhyaline, veins concolorous except basally and apically, where they are somewhat lighter. Veins of hind wings dark.

Structure.—Distinctly wedge shaped. Face flat, vertex very short medially, longer next the eyes, with posterior margin sinuate and extended behind eyes laterally. Pronotum slightly humped in lateral view, long; posterior margin concavely curved. Elytra long and slender, tapering apically, second cross vein absent.

External genitalia.—The abdomen is missing from the specimen examined, but Van Duzee gives the "ultimate ventral segment of the female but little longer than the penultimate, apex truncated, almost parallel with the basal. Valve of the male inconspicuous, broad triangular, its apex truncated, plates hardly twice the length of the valve, much shorter than the pygofers which together with the plates form a long, triangular segment."

Described from four specimens taken in Jamaica at Mandeville and Montego Bay and known from no other localities. A paratype,

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obtained through the kindness of E. P. Van Duzee, is the only example of this species examined by the writer. Types in the collection of the California Academy of Science.

AGALLIOPSIS CINCTA n. sp.

(Fig. 2, H, I; pl. 1, F)

Pale gray, resembling *A. anomala*, but more robust, with a faint transverse vitta on the elytra. Length of male 3 mm, of female 3.5 mm.

Color.—General ground color light gray. Front yellowish; sutures, sides of frons, and arms of inverted Y brownish. A tiny spot at inner margin of each ocellus and one on vertex above each ocellus fuscous; a larger spot at the inner margin of each eye black. A very fine, indistinct brown median line on posterior margin of vertex and anterior margin of pronotum. Pronotum with depressed anterior margin laterally and a small spot midway on each side smoky. Elytra uniformly grayish to subhyaline with a smoky black transverse vitta dorsally, half the distance back on the commissural line and broken at the claval sutures. In a somewhat teneral male that is at hand this vitta is not evident.

Structure.—Small, distinctly wedge shaped. Vertex very short medially, much longer next the eyes, posterior margin faintly sinuated and extending behind the eyes laterally. Anterior margin of pronotum strongly arched, posterior margin broadly rounded, lateral margins obsolete. Elytra long and tapering, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female long but retracted, lateral angles rounded, posterior margin truncate. The abdomen of the single male at hand is badly shrunken, but the plates are evidently united basally, the lateral margins parallel, and the tips bluntly pointed.

The small size and distinctive color will distinguish this species from others in the group.

Holotype female from Key Largo, Fla., August 9, 1930, R. H. Beamer. Paratypes, 1 female with the same data and 1 male from Homestead, Fla., May 16, 1928, E. D. Ball. Holotype in the University of Kansas collection; paratypes in collection of E. D. Ball and in the United States National Museum collection (catalog no. 43976).

AGALLIOPSIS HUACHUCAE n. sp.

(Fig. 1, K, L, M; fig. 13, L, M; pl. 4, C)

Resembling *A. oculata* but lighter, pronotum shorter, posterior margin of vertex less curved forward, female segment produced medially and male plates broader basally and more tapering. Length 4–4.25 mm.

Color.—Vertex and pronotum yellowish white, tinged with brown. Face with black marks as follows: Tip of clypeus, margins of frons, circles around ocelli, a large spot above each ocellus on anterior margin of vertex, a small spot above inner margin of each eye, and the inverted Y on vertex. Pronotum with a fuscous patch on anterior margin behind each eye, sometimes extending toward middle to small black spots in depressions each side of median line anteriorly. Faint median line and large spots midway on each side black. Scutellum with three black triangles having bases at anterior margin, a black dot each side of the median one, and a fourth black triangle having its base at the transverse furrow. Elytra brownish with light veins; hind wings somewhat darkened, veins fuscous.

Structure.—Very similar to *oculata* but with vertex longer medially and pronotum shorter and less humped in lateral aspect. Vertex about one half longer next the eyes than medially, posterior margin produced slightly beyond anterior margin of eyes medially and extending for a short distance behind eyes laterally. Pronotum depressed near anterior margin, posterior margin nearly truncate, lateral margins slightly longer than in *oculata*. Elytra long; venation as in *oculata*.

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External genitalia.—Last ventral segment of female three times as long as preceding segment, lateral angles strongly produced and rounded, central portion broadly produced from lateral angles to broadly rounded, slightly notched apex. Margin between apex and lateral angles slightly incurved. Male valve large, nearly square, appearing somewhat straplike. Plates broad at base, thin, closely appressed to pygofer, and tapering rather sharply to pointed, slightly divergent apices. Dorsocaudal angles of pygofer ending in short, stout spines.

Internal male genitalia.—In lateral view aedeagus slender, with a bracelike sheath enveloping median portion. Dorsal spine of tenth segment simple, stout, and slightly curved. In dorsal view aedeagus with a pair of long slender processes arising near the tip and extending laterally and slightly cephalad and another very short pair extending caudad and curved inward. In caudal view posterior margins of pygofer reflexed inward and bearing two broad, sclerotized spines, each of which ends in three sharp points dorsally on the inner margins.

Easily separated from closely related species by the distinctive genitalia of both sexes.

Holotype male, allotype female, and 1 male and 6 female paratypes from Huachuca Mountains, Ariz., August 2, 1927, R. H. Beamer. Holotype, allotype, and paratypes in the University of Kansas collection; paratypes in the collection of E. D. Ball and in the United States National Museum collection (catalog no. 43977).

AGALLIOPSIS FUSCOSIGNATA n. sp.

(Fig. 13, H, I; pl. 4, D)

Resembling *A. huachucae*, but smaller and more closely related to the *oculata* group. Length of male 3.5–3.75 mm, of female 3.75–4 mm.

Color.—Grayish white, tinted with brown. Face pale creamy with frontal sutures, antennal pits, and inverted Y on vertex fuscous; frons laterally with short transverse bars of brown; a black ring around each ocellus, a tiny black spot next the eye and a little higher than the ocelli, a pair of large black spots directly above ocelli on posterior margin of vertex, and a smaller pair at the inner corners of the eyes, also on the posterior margin of vertex. Pronotum with the following fuscous marks: A narrow median line, a pair of small spots close together and near anterior margin, and a large pair directly behind the large spots on vertex and about half way back; a faint spot near each lateral angle brownish fuscous. Posterior and anterior margins of pronotum sometimes smudged with brown. Basal triangles of scutellum black, barely showing behind pronotum; tip of scutellum fuscous; median transverse suture and spots in front of this brown. Elytra grayish brown, veins bluish white. Hind wings smoky, veins dark.

Structure.—Distinctly wedge shaped. Vertex very short medially, much longer next the eyes, posterior margin sinuately curved and extending behind eyes laterally. Pronotum roundingly humped in lateral view, lateral margins obsolete, posterior margin convexly rounding, slightly notched medially. Elytra long, tapering toward apices, second cross vein between sectors missing.

External genitalia.—Last ventral segment of female slightly longer than preceding segment, lateral angles broadly rounded, posterior margin nearly truncate but slightly sinuated each side of a very short and almost obsolete median tooth. Male valve not visible, plates united except at the tips, lateral margins slightly concavely curved for two thirds their length, then converging to form a bluntly pointed tip which exceeds pygofer.

Internal male genitalia.—Aedeagus and connective long, slender, and slightly curved; aedeagus with an elongate flap on each side, attached at the base and appearing sheathlike. Tip of aedeagus broadened and with a pair of short, lateral processes, the whole resembling a pick with a heavy shank and short points. Inner fork of style slender and curved dorsad and caudad, outer fork stout and blunt. Posterior margins of pygofer broadly rounded.

This species might easily be confused with the variety *minor*, since the general aspect and markings are the same, but the difference in size will serve to separate the two. A study of the habits of the two forms will undoubtedly bring to light a difference in food plants correlated with the difference in size.

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Holotype male and allotype female from Granite Dell, Ariz., July 17, 1929, E. D. Ball. Paratypes, 2 males and 8 females with the same data and 3 females from the above-mentioned locality, collected by Dr. Ball, October 6, 1929. Holotype, allotype, and paratypes in the collection of E. D. Ball. Paratypes in the United States National Museum collection (catalog no. 43978).

AGALLIOPSIS FUSCOSIGNATA var. MINOR n. var.

(Fig. 1, H, I, J; pl. 1, G)

Similar to the species but smaller. Length of male 3 mm, of female 3–3.25 mm.

Color.—Brownish gray, darker than typical *fuscosignata*, sometimes with a distinct whitish bloom. Face creamy gray; markings of face, vertex, pronotum, and scutellum as in *fuscosignata* but with the large spots on the vertex above the ocelli not extending over the margin posteriorly. Elytra gray-brown, veins bluish white.

Structure.—As in typical *fuscosignata*, but proportionately smaller.

Holotype male and allotype female from Tucson, Ariz., June 28, 1930, E. D. Ball. Paratypes, 14 females and 1 male from Tucson, Superior, and Apache Junction, Ariz., and Indio, Calif., collected on various dates by Dr. Ball. Holotype, allotype, and paratypes in the collection of E. D. Ball. Paratypes in the United States National Museum collection (catalog no. 43979).

AGALLIOPSIS CERVINA n. sp.

(Fig. 2, A, B; fig. 14, A, B)

Resembling *A. oculata* but slightly larger and with the elytra a deep brown. Length of male 4.25 mm.

Color.—General ground color deep brown. Upper margin of vertex creamy yellow, broad lateral margins of lora white, remainder of face brown, with fuscous marks as follows: Frontal sutures, sides of frons, antennal pits, semicircular spots at inner margins of ocelli, and inverted Y on vertex. Vertex with four black spots near posterior margin, the inner two above the ocelli, the outer two next the eyes. Pronotum brown, paler each side of median line; lateral margins white; black marks as follows: Anterior margin laterally, a median line which widens at both ends, and a large spot on each side posteriorly. Scutellum brown; basal triangles, depressed median dots, and tip black; lateral margins posteriorly creamy white. Elytra uniformly brown subhyaline with a broken transverse whitish vitta dorsally one third the distance back, and spots along commissural line whitish at the junction of the claval veins. Abdomen dark.

Structure.—Similar to *A. oculata* but slightly more robust. Vertex very short, longer next the eyes than medially, posterior margin slightly sinuate and extending behind the eyes laterally. Elytra long, second cross vein between sectors absent.

External genitalia.—Male valve transverse, collarlike. Plates long, united nearly to tips, lateral margins concave, tips rather broad and blunt, slightly exceeding pygofer.

Internal male genitalia.—Aedeagus flattened dorsoventrally, ribbonlike, in lateral view extending nearly straight caudad almost half its length, then curved broadly downward and the tip curved slightly upward. Tip of aedeagus with long, slender lateral processes that extend laterally and ventrally, curving anteriorly from base, the distal portion extending nearly straight laterad.

Most easily separated from *A. oculata* by the color pattern, the uniformly brown elytra, and the characters of the internal male genitalia.

Holotype male from Douglas County, Kans., June 1928, P. B. Lawson. Type in the University of Kansas collection.

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AGALLIOPSIS OCULATA (Van Duzee)

(Fig. 2, E, F, G; fig. 14, M; pl. 4, A)

Described by Van Duzee (*38, p. 38*) in 1890 as *Agallia oculata*. One of the largest of the North American species. Dark, with a pair of large black spots on the pronotum. Length of male 4 mm, of female 4.5–4.75 mm.

Color.—General ground color smoky brown. Front with fuscous marks as follows: Outer margins of frons marked with short transverse lines, a circle around and a longer transverse line under each ocellus, a small dot near each eye and a little above the level of the ocelli, another dot above each of these on the anterior margin of the vertex, a large dot on the anterior margin of the vertex directly above each ocellus, and a central, median, longitudinal line which widens dorsally. The median line and the four dorsally situated spots are visible on the vertex from above. Pronotum with black marks as follows: Two tiny spots near anterior margin, a narrow median line, two large spots on each side of median line midway between anterior and posterior margin, and a faint spot at each posterior angle. Scutellum with angles darkened and a pair of dots near anterior margin black. Elytra brown with whitish veins, sometimes apices and a median saddle slightly darkened.

Structure.—Long, wedge shaped. Vertex distinctly much shorter medially than next the eyes, extending behind the eyes laterally and with posterior margin curved far forward beyond anterior margin of eyes. Pronotum truncate behind, lateral margins very short, strongly oval, giving a somewhat humped appearance in lateral view. Elytra long, lacking second cross vein between sectors.

External genitalia.—Last ventral segment of female slightly longer than preceding segment, nearly truncate but usually slightly produced medially and faintly sinuate each side of median line. Ovipositor heavy, strongly exceeding pygofer. Male valve not visible, plates united basally for over one half their length, together broader basally, outer margins nearly parallel on median one third, curving gradually on posterior one third to appressed, bluntly pointed apices which exceed pygofer. Pygofer in lateral view rounded behind, with a tiny fingerlike projection on each side below the anal tube.

Internal male genitalia.—Aedeagus slender, in dorsal view bifid apically, tips diverging. A fleshy sheath on each side of penis extending nearly to tip.

Described from southern California from specimens collected by D. W. Coquillett. Common in the lower mountains of that area. Type in the collection of Iowa State College, Ames, Iowa. Specimens from the type series are now in the United States National Museum collection.

AGALLIOPSIS PENEOCULATA n. sp.

(Fig. 2, L, M, N; fig. 14, P; pl. 4, B)

Size and form of *A. oculata* but with the elytra concolorous except for an indistinct transverse smoky bar a little posterior to the forking of the first sector. Length of male 4 mm, of female 4.5 mm.

Color.—Lighter than *oculata*, with the fuscous markings of face, vertex, pronotum, and scutellum the same but usually smaller and less distinct. Elytra light-brownish subhyaline with a transverse smoky fuscous band across the middle of the clavus. Veins concolorous and indistinct.

Structure.—Distinctly wedge shaped, much like *oculata* in form. Vertex distinctly shorter medially than next the eyes, posterior margin sinuated and extending behind the eyes laterally. Pronotum with posterior margin nearly straight, lateral margins obsolete. Elytra long and tapering, about as in *oculata*, the second cross vein absent.

External genitalia.—Last ventral segment of female with posterior margin broadly, convexly rounded, about as in *oculata* but not sinuate. Valve of male not visible, plates long, united except distally, lateral margins concave on basal two thirds, tips bluntly rounded.

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Internal male genitalia.—Aedeagus long and slender but stouter than in *oculata*, the tip in dorsal view very broad and appearing somewhat bilobed, not forked as in *oculata*. Penis sheath consisting of a short fleshy flap on each side but not attached to the penis.

Although strongly resembling *oculata* in size and general appearance, this species is easily separated by the lighter ground color, the transverse smoky band on the elytra, and the internal male genitalia.

Holotype male and allotype female from Lapeer, Mich., August 24, 1919, E. D. Ball. Paratypes, 1 male and 1 female, with the same data, 1 female from Gloversville, N.Y., C. P. Alexander, 1 male from Batavia, N.Y., August 13, 1915, H. H. Knight, and 1 female from Georgetown, Conn., September 23, 1910. Holotype and allotype in the collection of E. D. Ball, paratypes in the collection of C. E. Olsen and in the United States National Museum collection (catalog no. 43980).

AGALLIOPSIS DUBIOSA n. sp.

(Fig. 2, J, K; fig. 14, K, L)

Light orange yellow with four tiny black spots on the vertex. Length of male 4.25 mm.

Color.—Orange yellow with a faint whitish bloom. Face pale with faint brownish markings and a tiny fuscous spot at the inner margin of each ocellus. Vertex with four small black spots near posterior margin, one pair above the ocelli, and one pair next the inner corners of the eyes. Pronotum a deeper orange on anterior and posterior margins. Scutellum lighter on the anterior median portion and on lateral margins each side of the transverse suture. Elytra light yellowish-orange subhyaline, veins mostly concolorous and obscure, sometimes a little darker than the elytra and occasionally broadly milky white for short distances.

Structure.—Elongate, slender, vertex short, a little longer next the eyes than medially, posterior margin feebly sinuate and extending only a very little behind eyes laterally. Pronotum rather short, posterior margin straight. Elytra long, margins nearly parallel, second cross vein between sectors missing.

External genitalia.—Male valve long, nearly rectangular, slightly wider basally than median length, lateral margins slightly converging. Plates a little longer than valve, subtriangular, tips blunt.

Internal male genitalia.—Aedeagus long, extending first dorsad and then broadly bent so that the distal portion extends caudad, the base quite stout but the distal portion slender; a pair of rather stout processes arising a little before the middle, each of these bearing on the inner margin a short, pointed projection; another pair of processes extending laterally from just before the tip, these long and slender. Dorsal spine of tenth segment broad, tip hooked downward, posterior margin dorsally, coarsely serrate. Pygofer with a small hook on each posterior margin, these extending inward and a little upward and hooked caudally.

Holotype male and 1 paratype male from the Huachuca Mountains, Arizona, August 1, 1927, R. H. Beamer. Holotype in the University of Kansas collection; paratype in the United States National Museum collection (catalog no. 43982).

AGALLIOPSIS TENELLA (Osborn and Ball)

(Fig. 3, K, L)

Described as *Agallia tenella* by Osborn and Ball (*28, p. 56–57*) in 1898. Elongate, the elytra with two cross veins between sectors and the female segment triangularly produced and notched at the apex. Length of female 4.25 mm.

Color.—General ground color pale creamy. Face with fuscous marks as follows: Tip of clypeus, frontal sutures, antennal pits, inverted Y on vertex, and circles around ocelli; short, transverse marks laterally on frons brown to fuscous.

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Elongate spots on vertex above ocelli brown to fuscous, those next the eyes round and brownish fuscous. Pronotum with the following markings golden brown in the type: Depressed anterior submargin laterally, narrow median line, and oblique oval spots on each side of median line; these markings fuscous in fully colored specimens. Broad posterior margin of pronotum unmarked and distinctly paler than anterior portion. Scutellum with basal triangles brown to fuscous, narrow median line and two small spots before transverse suture brown; transverse suture and a triangular area back of this brownish fuscous. Elytra faint brownish subhyaline, a faint brownish spot along commissural line between the claval veins and another just beyond the clavus; veins of elytra bluish white. Hind wings with veins dark.

Structure.—Distinctly wedge shaped, resembling *novella* but much more elongate. Vertex very short medially, pronotum short, lateral margins obsolete, posterior margin truncate. Elytra long and slender, slightly tapering, tips rounded, venation distinct, second cross vein between sectors present, the third anteapical cell nearly as long as the second.

External genitalia.—Last ventral segment of female with lateral margins short, the posterior margin triangularly produced and tip shallowly notched medially.

The shape of the female segment and the presence of the second cross vein between the sectors of the elytra are the most distinctive characters of this species. Osborn and Ball described *tenella* from 3 female specimens, 1 from Orizaba, Vera Cruz, Mexico, January 9–16, 1892, and 2 from Córdoba, Vera Cruz, Mexico, January 23, 1892, all collected by H. Osborn. Examination of the type material shows that there were two species involved, and since no specific localities were mentioned in the original description, the species from Orizaba, which has the characters of wing venation and form of female genitalia mentioned by Osborn and Ball, is here considered as representing *tenella*, while the species from Córdoba, which lacks the second cross vein, has the female segment roundly and very slightly produced, and differs in other respects, is a distinct and apparently undescribed species. Ball (*4, p. 127*) placed *producta* Baker (nec. Osborn and Ball) as a synonym of *tenella* Osborn and Ball, but an examination of Baker's types shows that they represent a distinct species. Thus there have been no less than three species confused under the single name *tenella*, which, as it now stands, is known from only the female sex. Records of *tenella* from the West Indies no doubt refer to *albidula* Uhl. Examination of the type series of *tenella* was made possible through the kindness of C. J. Drake and H. H. Knight. Type in the collection of Iowa State College, Ames, Iowa.

AGALLIOPSIS BRUNNEA new name

(Fig. 3, A, B, C; fig. 14, N, O)

Described by Baker (*2, p. 200*) in 1898 as *Agallia producta*, but this name was used first by Osborn and Ball (*28, p. 52*). Smaller than *tenella*, and the elytra without the second cross vein between sectors. Length of male 3.5 mm, of female 3.75 mm.

Color.—General ground color pale olivaceous brown. Face bright yellow, without markings except the black antennal pits and dirty circles bordering ocelli. Vertex with a round black spot above each ocellus, one next each eye, and a transverse black spot medially on the posterior margin. Pronotum with a faint median line and a pair of tiny spots anteriorly. Borders of pronotum lighter. Basal triangles of scutellum and spots before transverse suture fuscous. Elytra subhyaline, veins very faintly brown.

Structure.—Not so distinctly wedge shaped as *tenella*. Vertex short, pronotum with lateral margins obsolete, posterior margin truncate or slightly concave.

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Elytra long, scarcely tapering, second cross vein between sectors absent, venation obscure.

External genitalia.—Last ventral segment of female with lateral margins short, posterior margin triangularly produced, tip not notched. Male valve not visible, plates very long, slender and united for one half their length, widening rather abruptly at about the middle, then gradually narrowing to bluntly rounded tips which exceed pygofer.

Internal male genitalia.—Shanks of styles long and slender, forks short, together appearing almost clublike. Connective stout and nearly straight, the basal end swollen and forcepslike in dorsal view; attached to the styles by a long, slightly sclerotized, straplike process, while a similar process attaches the distal end of the connective to tenth segment. The aedeagus extends caudad from the distal end of the connective, forming an acute angle with the connective. Aedeagus slender, rather abruptly, sinuately bent near the tip, which is very slender and ends in a pair of forks which resemble outside calipers. Styles with numerous long, fine hairs on the inner surfaces. The internal genitalia of this species are unique in that there is a complete connection between the styles and the anal tube, and that a portion of the style-aedeagus connective is very much elongate and poorly sclerotized.

The external genital characters of either sex, together with the size and markings, should be sufficient to distinguish this species, while the internal male genitalia are unlike those of any other known species in the genus.

Baker described his *producta* from Mexico, but the name was preoccupied by Osborn and Ball's species from the same locality. Ball (*4, p. 127*) in 1900 mentioned that *producta* was preoccupied, but placed Baker's species as a synonym of *tenella* Osborn and Ball. Examination of the type material of both species, however, convinces the writer that Baker's *producta* is a valid species; so the name *brunnea* is here applied. Specimens at hand are from Medellin, Vera Cruz, Mexico, and La Ceiba, Honduras. Cotypes in the United States National Museum collection (catalog no. 43981).

AGALLIOPSIS MAGNIFICA n. sp.

(Fig. 3, I, J; fig. 14, Q, R)

Light brown with fuscous markings. Resembling *A. oculata* but even larger. Length of male 5.25 mm.

Color.—General ground color yellowish brown. Face light with brownish fuscous marks as follows: Frontal sutures, short dashes on frons laterally, inverted Y on vertex, and rings around ocelli; spots on posterior margin of vertex above ocelli fuscous and those at inner corner of eyes brown. Pronotum with fuscous median line that does not reach anterior margin, a very faint dark spot on each side near anterior margin, a large fuscous spot on each side of the disk, and a smaller fuscous spot near each lateral margin. Basal triangles of scutellum black, transverse suture, round depressions anterior to this, and a faint median line brownish fuscous. Elytra uniformly brownish subhyaline, veins paler.

Structure.—General shape of *oculata*, vertex very short medially, longer next the eyes, hind margin sinuate and extending behind eyes laterally but not so much as in many of the species. Pronotum distinctly humped in lateral view. lateral margins almost obsolete, hind margin very slightly angularly concave. Elytra long, rather slender, second cross vein between sectors missing.

External genitalia.—Male valve almost rectangular, slightly longer than basal width and with lateral margins very slightly converging. Plates long and slender, united except at tip, lateral margins nearly parallel for a short distance, then gradually converging. Tips bluntly rounded and plates curved upward close to hind margins of pygofer.

Internal male genitalia.—Aedeagus heavy, almost straight, the tip with a pair of rather heavy projections which extend laterally and anteriorly in the same plane with the aedeagus. Pygofer with posterior margins heavy, dorsally forming a pair of stout, heavy, inward-projecting spines. Anterior to these are a pair of

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very slender spines, also projecting directly inward. Tenth segment without distinct spines but ending in sharp points caudally.

Although described from a single specimen, the large size, together with the distinctive markings and male genitalia, should easily separate this species from any previously described form.

Holotype male from Ayotla, Mexico, 11–4. No other data. Type in the collection of E. D. Ball.

AGALLIOPSIS ANCORALIS n. sp.

(Fig. 3, G, H; fig. 13, N, O)

Golden brown, resembling *A. tenella*, but with the second cross vein in the elytra absent and the posterior margin of the pronotum not pale. Length of male 4 mm.

Color.—General ground color golden brown. Face with fuscous marks as follows: Frontal sutures, marks laterally on frons, antennal pits, circles around ocelli, and inverted Y on vertex. Base of inverted Y broadened at apex of vertex to form a median spot from above. Vertex with a large fuscous spot on posterior margin above each ocellus and a smaller fuscous spot at the inner angle of each eye. Pronotum with a median fuscous stripe which broadens posteriorly and a fuscous spot covering each of the anterolateral depressions. Posterior margin a little darker with a brown lobelike spot extending anteriorly on each side, laterad of of these indistinct clouds of brown. Scutellum with three basal and one apical fuscous triangles. Elytra mostly brownish subhyaline, with the veins pale, especially along the commissural line, and an indistinct transverse vitta of brown just posterior to the forking of the sectors.

Structure.—Vertex short, a little more angular than is usual in the genus. Pronotum short, with the anterolateral depressions quite distinct and posterior margin only slightly concave. Elytra slender, tapering to bluntly rounded apices, second cross vein absent.

External genitalia.—Male valve long, almost quadrangular, a little narrower distally than basally, and with lateral margins slightly concave. Plates almost triangular, lateral margins slightly convex, apices pointed and equaling pygofer in length.

Internal male genitalia.—Aedeagus rather stout basally, extending dorsocephalad from connective, then bending sharply caudad, slender distally, tip in dorsal view anchor shaped but with the arms almost parallel. In lateral view these arms are much broadened distally. Pygofer with hind margins bearing two hooklike projections on each side. Posterior margins of tenth segment produced into fingerlike projections at either angle.

The markings and male genital characters are sufficient to distinguish this species.

Holotype male from Jalapa, Vera Cruz, Mexico, collected June 20, 1898. Type in the collection of E. D. Ball.

AGALLIOPSIS EXILIS n. sp.

(Fig. 4, A, B; fig. 13, P, Q)

Distinct from all other species in the genus because of the very large elytra. Length of male 4.75 mm, length of elytra alone 4 mm.

Color.—General ground color dirty brownish gray, clypeus infuscated, frons, except basally, black, frontal sutures dark. Vertex with black marks as follows: Inverted Y, spots laterally next the eyes, projections from these which encircle ocelli, and large spots on margin above ocelli. Pronotum with anterior margin on median one fourth black; a median line on anterior two thirds and spots laterally on disk also black; lateral margins infuscated. Scutellum with dim fuscous triangles basally. Elytra dirty subhyaline, veins a little paler.

Structure.—Head and thorax a little depressed, vertex and pronotum short, the latter with posterior margin concave. Elytra extremely long and broad, scarcely tapering distally, the apices broadly rounded. Second cross vein between sectors absent.

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External genitalia.—Male valve very long, nearly twice as wide basally as distally, lateral margins convex. Plates small, triangular, lateral margins convex, apices bluntly pointed.

Internal male genitalia.—Aedeagus much as in *A. ancoralis*, but more slender and with the lateral processes at the apex forked and not widened in lateral view.

The specimen upon which the description is based is somewhat teneral, which may account for some, but not all, of the depressed appearance of the head and thorax. However, the size of the elytra is so distinctive that the writer feels that the description from a single specimen is justified.

Holotype male from Trinidad, Colo., 9,000 feet, August 8, 1925, C. J. Drake. Type in the collection of E. D. Ball.

AGALLIOPSIS VARIABILIS n. sp.

(Fig. 3, D, E, F; fig. 13, R, S; pl. 1. E)

Most closely allied to *A. novella* and *A. anomala* but with the second cross vein between sectors of the elytra present and the third anteapical cell large. Length of male 3.5–3.75 mm, of female 3.75–4 mm.

Color.—General ground color very light yellowish brown. Front variously marked with light brown, a median line, a round dot above each ocellus, and an irregular spot against each eye visible on anterior margin of vertex from above. Eyes reddish brown. Pronotum with coppery brown to fuscous marks as follows: A narrow median line, one pair of elongate, longitudinal spots anteriorly and two smaller pair posteriorly, and anterior margin laterally. Scutellum with basal angles and median transverse furrow brown, remainder yellow. Elytra light brown to fuscous basally, fading to subhyaline apically, veins mostly creamy white. Two dark areas in clavus along commissural line and cells of corium often infuscated. Hind wings with veins dark.

Structure.—Not so distinctly wedge shaped as *oculata*, width across elytra about equal to width of head. Hind margin of vertex almost semicircular between eyes and produced slightly beyond anterior margin of eyes. Vertex much shorter medially than next the eyes, extending behind eyes laterally. Posterior margin of pronotum slightly concave, lateral margins very short, angles broadly curved. Elytra long, second cross vein between sectors present, third anteapical cell two thirds as long as second.

External genitalia.—Last ventral segment of female distinctly longer than preceding segment, posterior margin broadly but shallowly excavated. Ovipositor long, strongly exceeding pygofer. Male valve large, truncate behind, plates rather small, outer margins straight and slightly converging, apices slightly diverging and bluntly rounded. Plates exceeding pygofer.

Internal male genitalia.—Style apparently consisting of two sclerites but actually of one, posterior portion of inner fork footlike. Dorsal processes of aedeagus in lateral view very broad medially, tapering to a blunt point distally. Dorsal spines of tenth segment strongly curved, inner margins with footlike projections, tips sharply pointed and slightly reflexed. Viewed from above, the dorsal process of the aedeagus is narrow, the ventral process heavy and ending in a sharp median projection and a pair of long, caudally curved lateral processes.

This species may be separated from any other known forms by the markings of the vertex and pronotum, the size, the distinctive male genitalia, and the presence of the second cross vein between the first and second sectors of the elytra, making three anteapical cells instead of the usual two.

Holotype male and allotype female from Zion National Park, Utah, August 13, 1929, P. W. Oman. Paratypes, numerous specimens of both sexes with the same data and others from Grand Canyon, Tucson, Santa Rita Mountains, Granite Dell, and Baboquivari Mountains, Ariz.; Tehachapi and Riverside, Calif.; and Douglas County, Colo. Holotype, allotype, and paratypes in University of Kansas collection; paratypes in the collection of E. D. Ball and in the United States National Museum collection (catalog no. 43983).

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AGALLIOPSIS ANOMALA (Baker)

(Fig. 2, C, D)

Described by Baker (*2, p. 200*) in 1898 as *Agallia anomala*. Allied to *A. novella* but smaller and more slender and with the female segment only shallowly excavated. Length of female 3.5–3.75 mm.

Color.—General ground color pale brownish gray. Face above pale with fuscous marks as follows: Clypeus, sides and tip of frons, frontal sutures, antennal pits, arms of inverted Y on vertex, small triangular spot next each eye in line with the ocelli, and small spots inside of and bordering each ocellus. Base of inverted Y on vertex brown; small spots on posterior margin of vertex above ocelli and similar spots next each eye fuscous. Pronotum with a faint brown median line, a pair of faint brown spots midway on each side, and with the anterior margin laterally brownish. Scutellum pale, depressed transverse suture and depressed spots in front of this pale brownish. Elytra mostly subhyaline, two brown areas in clavus along commissural line and cells of posterior half of corium embrowned. Veins partly yellowish white, mostly concolorous with membrane.

Structure.—Vertex strongly rounded; pronotum with lateral margins obsolete, posterior margin broadly rounding, scarcely subtruncate. Elytra long, more tapering than those of *novella*, venation mostly obscure; second cross vein between sectors nearly always absent; when present, the third anteapical cell very short.

External genitalia.—Last ventral segment of female much narrower than that of *novella*, lateral margins straight, lateral angles rounded, posterior margin shallowly, roundly excavated.

A. anomala may be separated from closely related species by the shape of the female genitalia and the fact that it has only one cross vein between the sectors of the elytra.

Baker described *anomala* from two females from the State of Vera Cruz, Mexico. Ball (*4, p. 127*) indicated that it might be a synonym of *tenella* Osborn and Ball, but an examination of Baker's specimens convinced the writer that they represent a distinct and valid species. Several specimens are at hand from Mexico, and a specimen from Costa Rica and another from Guatemala seem to belong here, extending the known range of the species far south. At present known only from the female sex. Cotypes in the United States National Museum (catalog no. 43973).

AGALLIOPSIS NOVELLA (Say)

(Fig. 3, M, N, O; fig. 14, C, D, E, F, G, H, J; pl. 1, D)

Described by Say (*31, p. 309*) in 1831 as *Jassus novellus* and redescribed by Forbes (*15, p. 22*) in 1884 as *Macropsis nobilis*. Wedge shaped, yellowish white to brown, marked with fuscous and black. Length of male 3–3.5 mm, of female 3.5–4 mm.

Color.—Usually light testaceous, often darker, the males sometimes almost fuscous. Face yellowish, variously embrowned, inner margins of ocelli black. Hind margin of vertex with a round black spot above each ocellus and a smaller, slightly oblong one next each eye. Pronotum with a median brown stripe and a fuscous spot on each side about equidistant from the front and back margins. Dark specimens often have the hind margin broadly, and the anterior margin narrowly, brown or fuscous; in pale specimens the median line and lateral spots may be faint or obsolete. Scutellum with basal triangles fuscous. Elytra testaceous to brown, veins light. Hind wings smoky, veins dark.

Structure.—Slender wedge shaped. Vertex very short, much longer next the eye than medially; hind margin sinuated and extending behind the eyes laterally. Pronotum humped in lateral view, hind margin straight, lateral margins obsolete. Elytra long and slender, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female broad and greatly produced laterally, hind margin broadly, roundly excavated medially. The lateral lobes are usually rounded from the lateral margins, but sometimes quite pointed.

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Male valve large, hind margin truncate. Plates small, semitubular, tips bluntly rounded. Pygofer greatly expanded, exceeding plates both laterally and caudally; the plates scarcely covering the ventral opening to the genital chamber.

Internal male genitalia.—Style appearing to consist of two sclerites. Ventral portion of aedeagus stout and nearly straight, with a pair of slender lateral processes arising basally and extending alongside the aedeagus for more than half its length. Pygofer hooks of various shapes, coarsely serrate on inner margins. Dorsal spine of tenth segment short, tip bent abruptly upward.

The internal genital characters of the males of this form present a very interesting problem relative to their significance as specific characters. The pygofer hooks, as mentioned above and shown by the illustrations (fig. 14, F, G, H, I, J), are of various shapes, while the dorsal spines of the tenth segment and the lateral processes of the aedeagus show similar, though less distinct, variations. While the males from a single locality are invariably almost identical, the material at hand, although consisting of several hundred specimens from many localities in North America, is insufficient to determine the true significance of the genital characters. The examination of large series of males, together with host plant and habitat data, may definitely associate the internal genital characters with certain hosts, habitats, or distribution, but until this can be done it seems best not to name the various forms.

Say described *novella* from Indiana specimens, and the species is found throughout eastern North America. Specimens from the western part of the United States are larger and have more brown in their color patterns and will probably prove to be a distinct variety. Location of type unknown, probably destroyed.

AGALLIOPSIS NOVELLA var. TROPICALIS (Van Duzee)

(Fig. 14, I)

Described as *Agallia novella* var. *tropicalis* by Van Duzee (*41, p. 53*) in 1907. Size and form of tropical *novella* but the males much darker. The female genital segment is somewhat less deeply excavated and is slightly notched on each side half way to the base of the excavation. The male internal genitalia differ from those of typical *novella* only in that the lateral processes of the aedeagus are slightly longer and slenderer and closely appressed to the aedeagus.

At the time he described this form, Van Duzee indicated that further study might show it to be deserving of specific rank. It is possible, however, that examination of a large series of specimens from a wide range of localities will show this to be merely a dark extreme of a very variable species. Until such studies can be made it seems best to consider this as merely a variety of the typical northern form.

Types from Jamaica in the collection of the California Academy of Science. Mr. Van Duzee has kindly compared specimens from Jamaica with his types and reports them to be the same. Specimens almost identical with the Jamaican form are at hand from various localities in Mexico and Central America.

The genus AGALLIA Curtis

Vertex short and usually of almost uniform length, posterior margin broadly and evenly curved, not extended behind the eyes laterally, usually a black spot above each ocellus. Pronotum short, lateral margins almost obsolete, posterior margin straight or shallowly con-

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cave, entire surface finely granulate. Elytra usually broad, venation often obscure, and with 4 apical and either 2 or 3 anteapical cells. Internal male genitalia without pygofer hooks and with styles forked posteriorly. Nymphs with a pair of large lobate processes extending forward from the vertex.

Type of the genus, *Agallia consobrina* Curtis (=*puncticeps* Germar).

A careful study of the European species will probably show that few of the species here included in the genus are true *Agallia* and that most of them should be placed in a separate genus. The position of *nigricans* and *hystricula* is somewhat uncertain, but they are placed in the genus *Agallia* because of the character of the male styles and the fact that the pronotal striations are very faint. Further study may show that these forms deserve subgeneric rank. The status of *acuticauda* is also uncertain, in that it is the only species in the group with a dorsal spine on the tenth segment, a structure possessed by certain species of *Agalliopsis*.

Only the male sex of *hystricula* is known to the writer.

Key to the species of AGALLIA

1	Species typically black and yellow or blackish green and yellow; veins broadly marked with yellow; male plates slender, triangular, lateral margins straight and tips acutely pointed. West Indian species	2
	Species not as above	4
2 (1)	Disk of pronotum without black markings; posterior margins of male pygofer bilobed (fig. 14, V) *pulchra*, p. 30.	
	Disk of pronotum normally with black markings; posterior margins of male pygofer not bilobed	3
3 (2)	Posterior margin of male pygofer produced into long, ligulate processes which curve below the anal tube and up the opposite side (fig. 14, U). Female genital segment roundly produced *fascigera*, p. 29.	
	Posterior margins of male pygofer with only short processes (fig. 14, T). Female genital segment truncate *bicolor*, p. 28.	
4 (1)	Elytra reticulately veined *liturata*, p. 34.	
	Elytra not reticulately veined	5
5 (4)	Species typically yellowish brown to brown, with a large, oval, black spot on the vertex above each ocellus and 2 spots of approximately the same size and shape directly behind these near the posterior margin of the pronotum; other markings, if any, consisting of infuscation of areas medially and next the eyes on the vertex and anteriorly, laterally, and sometimes medially on the pronotum. Rarely with the posterior 2 spots nearly obsolete and the males of certain species almost wholly black	6
	Species with coloring not as above	26
6 (5)	Species very robust, length 2.75 mm or less. Aedeagus of male forked at tip (fig. 15, W), genital segment of female with a small median notch (fig. 7, B) *obesa*, p. 40.	
	Species elongate, length 3 mm or more; if robust, the length at least 3.5 mm. Aedeagus of male not forked at tip or, if forked, the outer margins of forks not sinuated. Genital segment of female unnotched medially or with a broad excavation	7
7 (6)	Males	8
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8 (7)	Aedeagus ending in a pair of long, lateral forks and a median tube which curves dorsad (fig. 16, E, F) *ingens*, p. 43.	
	Aedeagus not as above	9
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Pronotum without such a median line; spots usually 5 in number; if only 2, then situated near the anterior margin. Species sometimes testaceous brown without distinct markings on pronotum 44

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44 (43) Species testaceous brown without distinct markings on pronotum; length 3.5–4 mm. Female genital segment with posterior margin sinuated each side of a median notch (fig. 5, E); male plates long (fig. 5, F) ..... *configurata*, p. 36.
Species not as above 45
45 (44) Species brown with only one pair of oblique fuscous spots anteriorly on the pronotum. Length 4 mm ..... *bidigitata*, p. 36.
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46 (45) Posterior margin of female genital segment truncate (fig. 5, H); male pygofer with posterior margins coarsely serrate (fig. 15, A) *repleta*, p. 30.
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AGALLIA ACUTICAUDA n. sp.

(Fig. 4, C, D, E; fig. 14, S; pl. 4, E)

Pale brownish gray, with black spots on head, pronotum, and scutellum. Length of male 2.75–3 mm, of female 3.25 mm.

Color.—General ground color dull gray tinged with brown. Face creamy, frontal sutures and antennal pits fuscous; frons tinted with pink and small spots below ocelli black. Vertex with a short black median line, a large oval piceous spot on posterior margin above each ocellus, and a faint black spot on the anterior margin next each eye. Pronotum with a fine median line of fuscous, not reaching posterior margin, and a fuscous spot on disk each side of median line. Basal triangles of scutellum black. Elytra brownish gray, subhyaline; veins broadly bluish gray.

Structure.—Rather slender, similar to *munda*. Vertex short, a very little longer laterally than medially. Pronotum short, posterior margin truncate. Elytra long, slightly tapering, costal margin broadly bowed, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female very short, posterior margin slightly sinuate, truncate. Male valve narrow, nearly as long as apical width, apex truncate, slightly narrower than base, lateral margins straight. Plates extremely slender, together triangular, lateral margins straight, apices pointed and exceeding pygofer in length.

Internal male genitalia.—Aedeagus stout, U-shaped in lateral view, the ventral process being the longer and carrying the ejaculatory duct. Inner forks of styles sharply pointed. Dorsal spine of tenth segment heavy basally with ventral margin serrate, posterior portion slender and curved upward, ending in a sharp point. Posterior margins of pygofer bluntly rounded.

The long slender male plates and dull color with few markings will distinguish this species.

Holotype male from Port-au-Prince, Haiti, May 1, 1931, H. L. Dozier. Allotype female collected by Doctor Dozier at the same locality, May 5, 1931. Paratypes, 1 male with the same data as the holotype and 1 male from Doctor Ball's collection taken at Port-au-Prince, Haiti, in December. Holotype, allotype, and paratype in the United States National Museum collection (catalog no. 43984); paratype in the collection of E. D. Ball.

AGALLIA BICOLOR n. sp.

(Fig. 4, F, G, H; fig. 14, T; pl. 4, F)

Yellow and black; resembling *A. fascigera* but much darker. Length of male 3.25 mm, of female 3.5 mm.

Color.—General ground color yellow, but males frequently almost entirely black. Face wholly black to above ocelli except for the following yellow marks: Outer margins of lora, elongate spots inside antennal pits, and occasionally a

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median spot on the frons basally. Antennae yellow. Vertex yellow except an obliquely set black spot above each ocellus and dorsal extensions of the black frontal area along median and lateral lines. In the males the spots above the ocelli are usually fused ventrally with the dorsal margin of the black area on the front. Eyes fuscous. Pronotum of males wholly black except posterior margin and occasionally small spots each side of the center yellow. In the female the pronotum is essentially yellow, with the anterior margin, a median oval spot, and a pair of irregular spots posteriorly on each side black; the lateral spots barely fused with the posterior lateral margins of the median oval spots. Scutellum black except lateral margins behind transverse suture. Elytra black, with broad yellow marks on the inner margins, claval sectors, claval suture, and cubitus and a costal area apically subhyaline. Body black, legs yellow.

Structure.—Similar to *A. repleta* but more slender. Vertex of uniform length and evenly rounded. Pronotum short, posterior margin very slightly concave. Elytra long and rather narrow, costal margin nearly straight, venation obscure, second cross vein absent.

External genitalia.—Last ventral segment of female about twice as long as preceding segment, posterior margin truncate. Male valve large, transverse, and collarlike, nearly as long as broad, and posterior margin slightly produced medially. Plates slender, inner margins straight, outer margins parallel for a short distance, then abruptly converging to pointed, appressed apices which exceed pygofer in length.

Internal male genitalia.—Aedeagus long and slender, curved slightly ventrad in lateral view. Inner fork of style long and sharply pointed. Posterior margins of pygofer with short, rounded projections caudally, each bearing basally on the inside a stout, blunt, slightly hooked spine.

In the color pattern of the elytra this species is much like *A. fascigera*, but it may be easily distinguished from that and other species by the coloration of the head and pronotum and by the male genitalia.

Holotype male, allotype female, and numerous paratypes of both sexes from Guadeloupe, West Indies, July 30, altitude 3,000 feet, August Busck. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 43985); paratypes in the collection of E. D. Ball.

AGALLIA FASCIGERA Uhler

(Fig. 4, M, N, O; fig. 14, U; pl. 4, G)

Described as *fascigera* in 1895 by Uhler (*37, p. 82*) and again as *capitata* (*37, p. 83*). Yellow, with black or fuscous markings, about the size of *A. repleta* but with color pattern distinct. Length of male 3.5 mm, of female 3.75 mm.

Color.—General ground color light yellow. Frons, clypeus, and genae infuscated; a ring around each ocellus and a small oblong spot on anterior margin of vertex above each ocellus blackish. Eyes brown. Pronotum with black markings in the form of a narrow anterior margin, posterior submargin on middle one half, and a median bar connecting these. Scutellum dark basally. Elytra fuscous with bright yellow on the inner margins, sectors of clavus, claval suture, and cubitus except distally; distal two thirds of the anterior one half of the corium subhyaline. Hind wings hyaline, veins dark. Posterior margin of female genital segment dark brown.

Structure.—General shape of *Agallia repleta.* Vertex broadly rounded, slightly longer next the eyes than medially. Pronotum short, posterior margin straight. Elytra long, second cross vein absent.

External genitalia.—Last ventral segment of female about twice as long as preceding segment, posterior margin roundly produced from lateral margins, one half longer medially than laterally. Male valve large, transverse, collarlike. Plates slender, tapering to rather pointed apices which greatly exceed the short pygofer in length.

Internal male genitalia.—Aedeagus stout, very short, and curved sharply dorsad in lateral view. Posterior margins of pygofer bearing on each side a long ligulate extension which curves below the anal tube and up the opposite side to near the

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top of the tube, where it bends sharply caudad, the tip almost equaling the basal segment of the anal tube in length.

Uhler described both *fascigera* and *capitata* from the island of St. Vincent, the chief differences mentioned in his description being that *capitata* was broader and had different markings and a slender process at the tip of the scutellum. Although the Uhler specimens are all badly broken, there is no doubt that the series of four represents but a single species, evidently variable in the extent of the color pattern. The species is quite distinct from all others and may be easily recognized by the ligulate extensions of the male pygofer. Cotypes in the United States National Museum collection (catalog no. 10218).

AGALLIA PULCHRA DeLong and Wolcott

(Fig. 4, P, Q. R; fig. 14, V; pl. 1, I)

Described by DeLong and Wolcott (Wolcott *45, p. 259*) in 1923. Allied to *A. bicolor*. Face bright yellow, thorax and elytra yellow and black. Length of male 3–3.25 mm, of female 3.25–3.5 mm.

Color.—Face bright yellow, with dark antennal pits and black marks in the form of a spot on the vertex against each eye and a tiny elongate spot on the median line of vertex; a pair of tiny spots on posterior margin of vertex fuscous, these slightly closer together than ocelli. General ground color of pronotum bright yellow, fading to whitish on the posterior one third, with a black anterior margin and black marks in the form of a median line on the anterior one half and a spot each side of the middle anteriorly. Anterior black margin narrowed each side of middle. Discal portion of pronotum bright yellow, fading to whitish on posterior one third. Base of scutellum with three black triangles united basally, the two lateral ones longer than median one. Transverse suture and median pits faintly black, remainder of scutellum bright yellow. Elytra green to blackish, costal margin hyaline, veins broadly yellow or whitish, a yellow dorsal spot covering tips of claval veins. Hind wings smoky black, veins darker.

Structure.—Slender wedge shaped. Vertex of nearly uniform length, extending very slightly behind the eyes laterally. Posterior margin of pronotum slightly concave. Elytra long, slender; second cross vein absent.

External genitalia.—Last ventral segment of female broad, lateral angles produced, posterior margin broadly and shallowly excavated, slightly incised medially. Male valve small, triangular; plates slender, together triangular, lateral margins straight, tips pointed, exceeding pygofer in length.

Internal male genitalia.—Aedeagus slender, curved dorsad. Inner process of style produced beyond outer process much as in *A. bicolor*, but bearing a blunt ventral tooth. Posterior margins of pygofer bent inward, then produced caudad into bilobed flaps which lie in oblique planes, converging ventrally.

Described from specimens from Puerto Rico, and no other locality is represented in the material at hand. Male paratype examined. Types in the collection of D. M. DeLong.

AGALLIA REPLETA Van Duzee

(Fig. 5, G, H, I; fig. 15, A, B; pl. 1, H)

Described from Trinidad by Van Duzee (*41, p. 57*) in 1907. Olive-brown with two black spots on the vertex and usually five on the pronotum. Superficially identical with *A. lautus* (Stål). Length of male 2.75–3 mm, of female 3–3.5 mm.

Color.—General ground color light olivaceous brown, sometimes darker and lacking the greenish tinge. Face with black markings as follows: Antennal pits, a ring around each ocellus, arms of inverted Y, sides of frons, clypeus, except basally, and a spot on anterior margin of vertex above each ocellus, these sometimes fused below with the rings around ocelli. Pronotum typically with 5 black spots, a central elongate one, 2 near anterior margin and close together and 2 near posterior margin more widely separated. In pale specimens the posterior

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pair of spots, and sometimes the central one also, may be indistinct or entirely missing, while in exceedingly dark forms the anterior pair may be fused with a dark area along the front margin of the pronotum and the central one fused with the two posterior spots to form a wide dark area along the hind margin of the pronotum. Scutellum yellowish with triangular black spots in basal angles and a pair of small, round black spots in front of the transverse furrow. Elytra typically with cells fuscous and veins broadly margined with greenish yellow, but exceedingly dark specimens have few or none of the veins pale.

Structure.—About the size of *A. lingula*, but less robust. Vertex very slightly longer next the eye than medially. Pronotum short, hind margin nearly straight or slightly concave. Elytra long, greatly exceeding abdomen in length, second cross vein absent.

External genitalia.—Last ventral segment of female about 1½ times as long as preceding segment, a little longer medially than laterally, lateral angles slightly produced and posterior margin nearly truncate. Male valve large, wider than long, narrowing distally and with hind margin nearly truncate. Plates rather broad at base, narrowing gradually to truncate tips. Outer margins slightly longer than inner, the tips of the plates together thus having an incised appearance. Plates a little narrower than those of *A. lautus*. Pygofer truncate behind in lateral view, without heavy spinelike projections below.

Internal male genitalia.—Aedeagus in lateral view stout, arched, and ending in an obliquely set headlike knob with a pair of short projections dorsally and two pairs ventrally. Hind margins of pygofer angled dorsally, with corners turned inward and each bearing a stout spinelike projection.

Externally this species appears to be identical with what the writer believes to be *A. lautus*, but the male genitalia lack the long, curved dorsal spine of the tenth segment and the spinelike projection of the ventral portion of the hind margins of the pygofer characteristic of that species (fig. 15, C, D), and the form of the tip of the aedeagus is different. Stål (*35, p. 55*) described *lautus* as a *Bythoscopus* from Rio de Janeiro, Brazil, in 1860.

A. repleta was described from Trinidad from a single pair. There are many examples at hand from various localities in Trinidad, Tobago, Republic of Panama, and Honduras. The specimens from Tobago, Panama, and Honduras are darker than those from Trinidad, many of the Honduras specimens being almost entirely black. In all structural respects the various examples seem to be identical; so the species is apparently subject to considerable color variation, as might be expected of a widely distributed form. However, since all variations from the light to the dark form are evident, there seems to be no basis for the application of varietal names. Mr. Van Duzee has compared specimens from Trinidad with his types and reports them to be the same. Types in the collection of the California Academy of Science.

AGALLIA MUNDA n. sp.

(Fig. 4, S, T, U; fig. 15, G)

Resembling *A. repleta* but paler, with the female genital segment excavated posteriorly and the male plates pointed. Length of male 3 mm, of female 3.25 mm.

Color.—General ground color dirty yellowish white. Antennal pits, distal half of clypeus, and spots on vertex above ocelli black; frontal sutures fuscous. Pronotum with an elongate fuscous spot on the disk, and a paler, more rounded one on each side a little more anteriorly. Scutellum with two triangular black spots basally. Elytra subhyaline, clavi faintly brownish yellow, veins light. Hind wings smoky, veins dark.

Structure.—Very much like *A. repleta* in size and shape. Vertex of uniform length and smoothly rounded. Posterior margin of pronotum straight. Elytra long, costal margin broadly curved, venation as in *A. albidula*.

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External genitalia.—Last ventral segment of female longer than preceding segment, lateral angles slightly produced and rounding, posterior margin roundly excavated, sometimes one fourth the distance to the base, often merely shallowly concave. Male valve large, collarlike, posterior margin truncate, length equaling width of hind margin. Plates small, narrowing rather abruptly to pointed tips, together triangular, exceeding pygofer in length.

Internal male genitalia.—Aedeagus in lateral view short, straight, and very broad, ending in two parts, the ventral one more slender and curved dorsally. Pygofer resembling that of *A. albidula.*

The size and the arrangement of the three pronotal spots of this species give it a striking resemblance to very pale examples of *A. repleta*, but the genital characters are very distinct. Further collecting will probably show this species to vary in color intensity, as do most of the related forms. Uhler had labeled the specimens upon which the foregoing description is based as his *albidula*, and they are probably those which he mentions as being in "incomplete states of coloration." However, both the color pattern and the genital characters readily separate these two forms.

Holotype male and allotype female from Mount Gay Estate (leeward side), Grenada, West Indies, H. H. Smith. Paratypes from Grenada, West Indies: 1 male and 1 female from Windsor, 1 female from Black Forest Estate (windward side), 1 female from Grand Etang (windward side), 1,900 feet, 1 male from Balthazar (windward side), 1 male from Wendome Estate (leeward side), all collected by H. H. Smith; and 1 female from the Botanical Gardens, November 12, 1918, Harold Morrison. Also one male from St. Vincent, West Indies. Types in the United States National Museum collection (catalog no. 43986).

AGALLIA MODESTA Osborn and Ball

(Fig. 4, I, J, K, L; fig. 15, E, F; pl. 1, J)

First described by Osborn and Ball (*28, p. 51*) in 1898. Redescribed the same year by Baker (*2, p. 200*) as *Agallia mexicana.* Very variable in color, usually a uniform light brown with four black spots. Length of male 3–3.5 mm, of female 3.5–3.75 mm.

Color.—Usually a uniform light yellowish brown with a pair of black spots on the vertex above the ocelli and a larger black pair behind these on the posterior margin of the pronotum, but the males often with an additional pair of black spots on the pronotum anteriorly, another small pair near the lateral margins of the pronotum, and the face and elytra infuscated. The males furnish nearly all variations in the extent of the black coloring, the dark extremes being almost entirely black, except for light areas on the vertex around the spots above the ocelli, the elytra in such cases being dark but subhyaline. The female apparently does not have the dark forms.

Structure.—Smaller and slightly less robust than *A. constricta.* Vertex of nearly uniform length, head slightly wider than pronotum. Pronotum with anterior margin evenly curved, posterior margin nearly truncate, but slightly concave. Elytra long, venation obscure, second cross vein absent.

External genitalia.—Last ventral segment of female truncate, or sometimes slightly excavated. Male valve large, slightly narrower distally than at base. Plates broad basally, tapering sharply on posterior one half, together rather bluntly pointed and equaling pygofer in length.

Internal male genitalia.—Aedeagus in lateral view short, curved slightly upward and the tip hooked dorsally. In caudal view the tip appears truncate, and the aedeagus bears before the apex a pair of small spines which extend cephalad. Hind margins of pygofer turned inward and with a short, inwardly projecting spine dorsally.

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Apparently a very common species throughout Mexico and Central America. A large series of specimens from Panama has the processes of the aedeagus longer and the pygofer a little longer, but as they are otherwise identical with Mexican specimens, they are not considered as representing a distinct form. Examination of specimens from localities between Panama and Honduras will no doubt show these characters to be variations. *A. modesta* was described from Vera Cruz, Mexico, and Baker's specimens, which he called *mexicana*, were from the same locality. Many specimens are at hand from various localities in Mexico and Honduras, as well as the series from Panama. Cotypes in the United States National Museum (catalog no. 44076).

AGALLIA LINGULA Van Duzee

(Fig. 6, A, B, C; fig. 15, H; pl. 2, D)

Described by Van Duzee (*41, p. 54*) in 1907. Resembling *A. constricta* but without the black spots on the pronotum and the female segment with a slender, median, ligulate process. Length 3.5–3.75 mm.

Color.—General ground color light yellowish brown, occasionally approaching brown. Front variously embrowned, vertex with a black spot on anterior margin above each ocellus. A median line on vertex and pronotum and various areas anteriorly and laterally on the pronotum brownish to fuscous, as are two triangular spots on the scutellum near the basal angles. Elytra brown, veins yellowish.

Structure.—As in *A. constricta*, vertex of uniform length, hind margin of pronotum straight. Elytra long, second cross vein between sectors either present or absent.

External genitalia.—Last ventral segment of female well produced, posterior margin truncate except for a slender median ligulate projection more than half as long as the remainder of the segment. Male valve broad, posterior margin straight. Plates broad basally, sharply tapering half their length, then produced to bluntly rounded appressed tips which exceed pygofer. Posterior margin of pygofer bluntly produced caudally.

Internal male genitalia.—In lateral view connective long and slender, forming a semicircle; aedeagus broad basally but quickly narrowed to a long, slender, filamentlike process curved back along the connective and forming nearly a complete circle. Smaller and with male genitalia distinct from those of *A. lingulata*.

Described from Jamaica. There are specimens at hand from the Canal Zone; Salvador; Honduras; Vera Cruz, Mexico; Brazoria, Hidalgo, Harris, Orange, and Cameron Counties, Tex.; and Natchitoches Parish, La., indicating a wide distribution through subtropical North America. Type in the collection of the California Academy of Science. A cotype of this species has been examined through the courtesy of Mr. Van Duzee.

AGALLIA LINGULATA Olsen

(Fig. 6, G, H, I; fig. 15, I; pl. 2, C)

Described and figured by Olsen (*22, p. 127*) in 1922. Resembling *A. quadripunctata* but smaller and slightly less robust, the female segment with a ligulate process much as in *A. lingula*. Length of male 3.5 mm, of female 3.75 mm.

Color.—Varying from light brown to fuscous, the males darker than the females. A pair of large black spots on anterior margin of vertex above the ocelli and

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another pair behind these near posterior margin of pronotum, all surrounded by lighter areas which merge into the ground color. Elytra brown to fuscous, veins pale, indistinctly so in very dark specimens. Hind wings smoky, veins dark.

Structure.—Vertex of almost uniform length, but anterior margin slightly flattened medially and thus shorter than next the eye. Pronotum short, 2½ times wider than long, posterior margin nearly straight. Elytra broad, venation as in *A. constricta.*

External genitalia.—Last ventral segment of female broad, truncate, with a narrow, median ligulate process very similar to that of *A. lingula* but broader and widened slightly at the tip. Male valve transverse, bisinuate, longer medially than laterally. Plates together nearly triangular, lateral margins shallowly concave and apices not quite touching.

Internal male genitalia.—In lateral view connective stout and slightly curved. Aedeagus with dorsal process short and stout, ventral process more slender, curving first dorsally and then a little ventrally near the tip. Entire aedeagus much heavier than and not nearly so strongly curved as in *A. lingula.*

The female of this species might easily be confused with that of *A. lingula* except for its larger size and dark pronotal spots. The males, however, are easily distinguished by the size, color pattern, and internal or external genitalia.

Described from specimens taken in New York and New Jersey. The writer has examined the holotype and male paratypes from New York and a pair of specimens from Rock Bluff, Fla., that agree with the type series in every particular, and has collected two males near the South River, south of Annapolis, Md. The Maryland specimens were taken May 26, 1932, from weeds growing in sandy soil and were thought at the time to be dark extremes of *A. constricta.* It is probable that the species will be found to be fairly common early in the season, but when an attempt was made to get additional specimens in July none could be found. The foregoing records indicate a wide distribution in a rather restricted habitat along the eastern coast of the United States. Types in the collection of C. E. Olsen and the American Museum of Natural History.

AGALLIA LITURATA Van Duzee

(Fig. 6, M, N, O; fig. 15, J)

Described by Van Duzee (*41, p. 56*) in 1907. Form of *A. producta,* but smaller and with the veins of the elytra reticulate. Length of male 3.5 mm, of female 3.75 mm.

Color.—Yellowish brown with markings of light brown to fuscous. Front variously embrowned, distal portion of clypeus, antennal pits, and circles around ocelli approaching fuscous. Spots on anterior margin of vertex above ocelli black and median area and irregular spots on posterior margin next eyes brown or fuscous. Pronotum with brown to fuscous marks on the posterior margin and lateral margins; the anterior margin laterally and a median line that becomes wider caudally, infuscated. Scutellum with triangular spots near basal angles brown, as is the transverse median furrow. Cells of elytra brown, veins whitish. Hind wings smoky, veins dark. Tip of projection of female genital segment dark.

Structure.—Vertex of uniform length and evenly rounded. Hind margin of pronotum slightly concave. Elytra with supernumerary veinlets in cells of both clavus and corium.

External genitalia.—Last ventral segment of female short laterally, median one half produced caudally 1½ times the length of the remainder of the segment. Projection tapering from base, tip less than one third as wide as the whole segment, ending in two lateral points with posterior margin angularly excavated between them. Male valve short, transverse. Plates together triangular, with lateral margins slightly concave, equaling pygofer in length. Pygofer broad basally, hind margins turned inward and bearing stout spines. Aedeagus often exposed.

Internal male genitalia.—Aedeagus stout, dorsal process short and heavy, ventral process longer and slightly curved.

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Easily distinguished by the reticulate venation of the elytra and the form of the external genitalia.

Described from Jamaica, and the writer has seen no specimens from other localities. Paratypes examined through the courtesy of E. P. Van Duzee. Types in the collection of the California Academy of Science; paratypes in the United States National Museum collection (catalog no. 43987).

AGALLIA ALBIDULA Uhler

(Fig. 5, A, B, C; fig. 15, K; pl. 2, E)

Described by Uhler (*37, p. 83*) in 1895 as *albidula* and redescribed by Van Duzee (*41, p. 55*) in 1907 as *basiflava*. Yellowish, marked with light brown, male plates small and female genital segment produced. Length 3.25–3.75 mm.

Color.—General ground color yellowish white. Face with brown markings as follows: Frontal sutures, tip of clypeus, antennal pits, frons laterally, inverted Y on vertex, and areas next the eyes. Spots on anterior margin of vertex above ocelli black. Pronotum with an elongate brown median spot, large irregular brown spots on each side posteriorly, and an anterior brownish area laterally. Scutellum with brown triangular basal spots; transverse furrow and two small round spots before furrow brownish fuscous. Elytra with cells brownish, veins basally yellow, distally paler; a dark area on each elytron dorsally in the angle formed by the first and second claval sectors and the inner margin of the wing, in front of this a yellow patch formed by the widening of the yellow margins of the claval veins. Central portion of posterior margin of female genital segment brown.

Structure.—Similar to *A. modesta* but larger and slightly more slender. Vertex of nearly uniform length and broadly rounded. Eyes a little swollen. Pronotum short, hind margin nearly straight. Elytra long and rather narrow, second cross vein absent.

External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, lateral angles produced and rounded, posterior margin rounded and slightly produced medially. The median portion is often a little elevated and compressed laterally, appearing sinuate. Male valve large and transverse, twice as wide as long, covering base of plates snugly at sides. Plates small, proportionately rather broad basally, narrowing sharply on basal one half, then tapering gradually, tips together rounded and exceeding the short pygofer. Pygofer in lateral view very short dorsally, hind margin sloping to a short ventral projection caudally.

Internal male genitalia.—Aedeagus stout, curved dorsally in lateral view, a membranous sheath on each side of tip.

Described from the island of St. Vincent. Specimens at hand are from various localities in Cuba, Isle of Pines, Puerto Rico, Dominican Republic, Jamaica, St. Vincent Island, St. Thomas Island, Trinidad, and the States of Rio de Janeiro, Minas Geraes, Matto Grosso, Pernambuco, and Manáos, Brazil. Apparently a very common species in the Tropics. It seems strange that this species was not among those described by Stål (*34, p. 290–292; 35, p. 54–55*), but the writer has been unable to find any of his descriptions that fit. Neither do Berg's descriptions (*7, p. 270–272; 8, p. 176–178; 9, p. 205–206*) seem to include this species. Van Duzee described his *basiflava* from Jamaica. The writer has examined a paratype of *basiflava* through the kindness of Mr. Van Duzee, and finds it to be only a pale example of Uhler's *albidula*. There are also, in the lot of *Agallia* sent the writer by C. E. Olsen, two males and a female of this species from Mount Desert, Maine. These examples check in every respect with typical *albidula*, and it seems probable that their occurrence so far north must be due to importation. In such

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case it would be interesting to know whether or not they have survived. Cotypes in the United States National Museum collection (catalog no. 10221).

AGALLIA CONFIGURATA n. sp.

(Fig. 5, D, E, F; fig. 15, L; pl. 2, F)

Pale yellowish brown. Allied to *A. producta* but smaller and paler, with the male plates longer and the female genital segment truncately sinuate. Length of male 3.5–3.75 mm, of female 3.75–4 mm.

Color.—Yellowish cinereous to dirty yellow. Face variously embrowned, vertex with a small fuscous spot on posterior margin above each ocellus. Anterior margin of pronotum, median line, and a large spot on each side posteriorly, faintly brown to brownish fuscous. Basal triangles of scutellum brown. Elytra pale to subhyaline, sometimes marked basally with brown or yellow, veins faintly whitish. Hind wings with veins dark.

Structure.—About as in *A. constricta.* Vertex very short and parallel margined, pronotum short, hind margin nearly straight. Elytra long and rather slender, strongly exceeding abdomen, second cross vein between sectors missing.

External genitalia.—Last ventral segment of female over twice as long as preceding segment, lateral angles well produced and rounded, posterior margin sinuate each side of a shallow, median notch. Male valve long and collarlike, about 1½ times as broad as long, inclosing base of plates laterally and with posterior margin slightly produced medially. Plates long and slender, narrowing sharply from base, tips slightly wider than median portion, bluntly pointed and exceeding pygofer in length.

Internal male genitalia.—Aedeagus long and slender, in lateral view sinuate. Tip not forked. Hind margins of pygofer produced and somewhat lobed next the plates.

Most easily separated from closely related species by the genital characters. As in most members of the genus, the color varies considerably in intensity, but the pattern is constant and quite distinctive.

Holotype male and allotype female from Mitchell Grove, Bayamon, Puerto Rico, June 26, 1917, Harold Morrison (251). Paratypes, 10 males and 2 females with the same data; 4 males and 1 female from Stanwood Grove, Bayamon, Puerto Rico, June 26, 1917, Harold Morrison (252); 3 males and 2 females from Parkhurst Grove, Bayamon, Puerto Rico, June 26, 1917, Harold Morrison (250); and 12 males and 2 females from Department of Agriculture grounds, Port of Spain, Trinidad, October 24, 1918, Harold Morrison (A-818).

There are also specimens at hand from the Dominican Republic and Corumba, Brazil. The South American specimens should not be confused with a closely related and apparently undescribed species which has the female genital segment similar to that of *A. albidula* and the second cross vein present in the elytra. Types in the United States National Museum collection (catalog no. 43988).

AGALLIA BIDIGITATA n. sp.

(Fig. 5, M, N, O; fig. 15, S)

Similar in size and form to *constricta* but with a golden-brown tinge and the female segment with a pair of short, fingerlike processes. Length 4 mm.

Color.—Head, thorax, and scutellum golden brown, clypeus and frontal sutures embrowned. Antennal pits black, inner margins of ocelli and oblique, oblong spots on vertex above ocelli fuscous, as are a pair of spots directly behind these and visible on the vertex below the somewhat elevated posterior margin. Pronotum with anterior submargins laterally and a pair of spots on each side of

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median line anteriorly dark brown. Basal triangles of scutellum brown. Elytra brownish subhyaline, the darker hind wings and dorsum giving the clavi a dirty brown appearance.

Structure.—Similar to *constricta* but more elongate. Vertex short and of uniform length, very slightly elevated behind but not as in *Agalliopsis*. Pronotum very short, hind margin straight. Elytra long, extending well beyond tip of abdomen, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female rather short, the posterior margin with a short, bluntly rounded, fingerlike process on each side about half way between middle and lateral margins of segment. Male valve large and collarlike, plates small and slender, turned upward behind and difficult to see.

Internal male genitalia.—Aedeagus broad and boxlike or troughlike, with a hooked spinelike process on each side dorsally. Connective long and threadlike, styles short and stubby. Hind margins of pygofer produced into two lobes on each side, the lower ones smaller and more rounded, both pairs bearing numerous setae.

Either the female genital segment or the male genitalia will serve to distinguish this species.

Holotype female and allotype male from Cacao, Trece Aguas, Alta V. Paz., Guatemala, Schwarz and Barber; one female paratype from Puerto Barrios, Guatemala, April 20, 1923, E. G. Smyth. Holotype in the collection of E. D. Ball, allotype and paratype in the United States National Museum collection (catalog no. 43989).

AGALLIA CONSTRICTA Van Duzee

(Fig. 5, P, Q, R; fig. 15, O, P; pl. 1, L)

Described by Van Duzee (*40, p. 90*) in 1894. Light brown with black spots on vertex and pronotum, less robust than *A. quadripunctata* and with the male genital plates constricted medially. Length of male 3.25 mm, of female 3.75 mm.

Color.—Typically light brown, the males frequently approaching fuscous. Front variously embrowned or infuscated, a pair of black spots on the anterior margin of the vertex above the ocelli and another pair behind these on the posterior margin of the pronotum. Median line, broad anterior margin laterally, and lateral submargin golden brown to fuscous. Elytra brown to fuscous, veins paler.

Structure.—Distinctly more slender than *quadripunctata*. Vertex of uniform length; anterior margin of pronotum evenly rounded, posterior margin slightly concave, lateral margins very short. Elytra not so broad as in *quadripunctata*, greatly exceeding abdomen in length, second cross vein between sectors either present or absent.

External genitalia.—Last ventral segment of female more than twice as long as preceding segment, lateral angles well produced and rounded, central portion slightly longer, a shallow notch on the median line. Posterior one half of segment depressed laterally, leaving a median keel. Male valve large, plates narrowing from the rather broad base to median constriction, then widening caudally. Plates together rounded apically. Pygofer compressed, exceeding plates in length; in lateral view the posterior portion curved dorsad and slightly notched behind.

Internal male genitalia.—Aedeagus stout and slightly exceeding pygofer in length, tapering to a sharp point in lateral view, in dorsal view forked at the tip.

Van Duzee described *constricta* from specimens from New Jersey, Mississippi, and Florida. It is probably the commonest species of the *Agallia* group to be found in the southeastern part of the United States, and its range extends west to central Texas, Oklahoma, Kansas, and Nebraska, and north into Iowa, central Indiana, Illinois, and Ohio, and still farther north along the Atlantic coast. Type in the collection of Iowa State College, Ames, Iowa.

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AGALLIA CONSTRICTA var. CUBANA n. var.

(Fig. 6, J, K, L; fig. 15, Q, R)

Size and form of typical *constricta* but darker and with the hind margins of the male pygofer produced into two nearly equal lobes. Length 3.25–3.5 mm.

Color.—Similar to the darker extreme of *constricta*, particularly in that the markings of the vertex and pronotum are fuscous and that the elytra are dark brown with the veins broad and pale.

Structure.—Similar to typical *constricta*, the second cross vein of the elytra either present or absent.

External genitalia.—Last ventral segment of female with posterior margin subtriangularly produced and bluntly rounded, not constricted from the lateral margins to median ridge as in *constricta*. Male valve and plates about as in *constricta* but plates less constricted.

Internal male genitalia.—Aedeagus similar in lateral view to that of *constricta*, but heavier, broader, and with wider forks at tip in dorsal view. Posterior margins of pygofer bilobed, the lower lobes slightly larger than the upper ones.

Although the internal male genitalia are quite distinct in the character of the aedeagus and form of the pygofer, this form is nevertheless placed as a variety of *constricta* because of the great similarity of the external characters.

Holotype male, allotype female, and one female paratype from Caimito del Guayabal, Havana Province, Cuba, August 23, 1917, Harold Morrison. Types in the United States National Museum collection (catalog no. 43990).

AGALLIA PRODUCTA Osborn and Ball

(Fig. 5, S, T, U; fig. 15, M, N; pl. 2, A)

Osborn and Ball (*28, p. 52*) described this species in 1898 as *producta* and the same year Baker (*2, p. 199*) described it as *heydei*. Resembling *A. constricta* but larger and with the female segment more produced and narrow. Length of male 4 mm, of female 4.25–4.75 mm.

Color.—Very similar to *A. constricta*. Light yellowish brown, with antennal pits, spots on vertex above ocelli and on pronotum near posterior margin black. Front variously embrowned. Rings around ocelli and inverted Y on front fuscous. Median line and anterior margin and lateral margins of pronotum brownish. Elytra brownish, veins lighter.

Structure.—Form of *A. constricta* but larger, more slender than *A. quadripunctata*. Vertex of uniform length, pronotum nearly truncate behind, lateral margins short. Elytra similar to those of *A. constricta*.

External genitalia.—Last ventral segment of female strongly produced, suddenly constricted one third its length from the base, leaving an elevated median portion. Constricted portion folded under basal portion of segment laterally, then tapering to a rather narrow, truncate tip. Male valve short and broad, plates as in *A. constricta*, constricted medially and together broadly rounded at the tip. Pygofer compressed, exceeding plates, and with hind margin roundly excavated in lateral view.

Internal male genitalia.—Very similar to those of *A. constricta*, aedeagus broad in lateral view and with forked tip in dorsal view.

Described from Vera Cruz, Mexico, as was Baker's *heydei*. There are also specimens at hand from La Cieba and Tegucigalapa, Honduras. This species is differentiated from *constricta* chiefly by the greater size and the more produced genital segment of the female. There is considerable variation in these characters in both *constricta* and *producta*, and it is very likely that an examination of a large series of specimens from northern Mexico and southwestern Texas

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will show these to be only extremes of a single, variable form. Until such studies can be made it seems best to make no changes in the status of *producta*. Cotypes in the United States National Museum collection (catalog no. 44077).

AGALLIA PENECONSTRICTA n. sp.

(Fig. 6, P, Q, R; fig. 15, T)

Similar to, but smaller and slightly more robust than, *constricta*. Length 3.25 mm.

Color.—Tawny brown, face infuscated; a pair of fuscous to black spots on the vertex above the ocelli and a similar pair behind these near the posterior margin of the pronotum. Elytra brownish subhyaline, veins a little paler.

Structure.—Intermediate in form between *constricta* and *deleta*, vertex and pronotum very short, the latter truncate behind. Elytra broad but extending beyond the tip of the abdomen; venation obscure, second cross vein between sectors missing.

External genitalia.—Last ventral segment of female much as in *constricta*, hind margin very slightly sinuate each side of a faint median notch. Male valve transverse, collarlike, plates shorter and less distinctly constricted at the middle than those of *constricta*, narrowing from the base for one half their length, then almost parallel sided, tips together bluntly rounded.

Internal male genitalia.—Aedeagus almost straight, in lateral view broad basally and tapering gradually toward the tip, the tip broader from above and bearing at each side a short, truncate, parallel-sided process which is finely serrate on the posterior margin and which extends downward almost at right angles to the remainder of the aedeagus. At the base of each of these is a short, pointed tooth which extends caudad. Posterior margins of pygofer produced into short, truncate lobes.

The size, lack of color pattern, and characters of the male genitalia are sufficient to distinguish this species from all other described forms in the genus.

Holotype male and allotype female from La Ceiba, Honduras, F. J. Dyer. Types in the United States National Museum collection (catalog no. 43991).

AGALLIA DELETA Van Duzee

(Fig. 5, J, K, L; fig. 15, U; pl. 1, K)

Described as *deleta* by Van Duzee (*42, p. 210*) in 1909. Lathrop (*19, p. 120*) in 1917 described the same species as *immaculata*, but in 1919 (*20, p. 23*) placed his name as a synonym of *deleta*. Unicolorous tawny or golden brown; males usually darker, often fuscous. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Usually light brownish, occasionally with faint darker areas on pronotum of male. Eyes reddish brown. Elytra subhyaline but appearing darker because of the dark abdomen. Hind wings smoky. Dark males usually show pale areas dorsally.

Structure.—Very robust, form much as in *A. quadripunctata* but much smaller. Vertex of uniform length and evenly rounded, extending very slightly behind the eyes laterally. Elytra broad, venation as in *A. constricta*.

External genitalia.—Last ventral segment of female short, posterior margin truncate but often arched so as to appear concave. Male valve long and collarlike, median length exceeding lateral length and nearly equaling width. Plates small, rather broad basally but narrowed abruptly and with blunt tips which equal the pygofer in length.

Internal male genitalia.—Aedeagus in lateral view broad and almost straight, in dorsal view laterally compressed and with tip split for a short distance. Posterior margins of pygofer with small flaplike projections turned slightly inward.

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Van Duzee's specimens, upon which the original description was based, were from Florida, whereas Lathrop's were from the longleaf pine and coastal-marsh areas of South Carolina. C. E. Olsen has sent the writer specimens that he collected at Woods Hole, Mass., Rahway, N.J., Forest Hills, Long Island, and White Plains, N.Y.; the known range of this species is thus extended considerably northward along the Atlantic coast. Other specimens at hand are from Florida, Georgia, South Carolina, and Virginia. The writer has taken adults and last-stage nymphs in the short grass along the roadside in southern Georgia in January, an indication that they pass the winter season in both stages, at least in the southern part of the United States. Types in the collection of the California Academy of Science.

AGALLIA OBESA n. sp.

(Fig. 7, A, B, C; fig. 15, V, W; pl. 4, H)

Size of *A. deleta* but with the aspect of a very small *quadripunctata*. Length 2.5–2.75 mm.

Color.—About as in *quadripunctata*. Golden brown with two large black spots on vertex above ocelli and a similar pair behind these near the posterior margin of pronotum. Areas bordering spots usually creamy brown. Elytra brownish subhyaline, veins lighter.

Structure.—Quite robust, very much like *deleta* in this respect. Vertex of uniform width, eyes slightly bulbous. Pronotum very short, posterior margin straight or slightly concave. Elytra short and broad, sometimes barely exceeding tip of abdomen in length, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female slightly longer than preceding segment, posterior margin slightly notched medially. Male valve large, lateral margins oblique, posterior margin slightly produced medially and less than twice as wide as median length. Plates slender, longer than those of *deleta* and slightly more pointed, tips exceeding pygofer in length.

Internal male genitalia.—Aedeagus longer than in *deleta*, with tip curved downward. Tip forked, the forks more divergent than those of *deleta* and coarsely serrate below. Hind margins of pygofer produced into subtruncated, somewhat bilobate processes, broadly constricted basally.

Easily separated from Van Duzee's *deleta* by the large black spots on vertex and pronotum, and by the above-mentioned differences in the male genitalia. Dozier reports that he collected the species from the short grass in flat pine woods, and it will probably be found to occur throughout the Gulf region in a similar habitat.

Holotype male and allotype female from Biloxi, Miss., August 1, 1921, H. L. Dozier. Paratypes, 3 males with the above data; 1 male and 2 females from Merrill, Miss., August 9, 1921; 1 male and 1 female from Hattiesburg, Miss., August 10, 1921; 1 female from Laurel, Miss., August 12, 1921; and 1 female from Gulfport, Miss., August 1, 1921, all collected by H. L. Dozier; 1 female from Woodville, Miss., July 25, 1921, C. J. Drake; 1 female from New Augusta, Miss., August 10, 1921, C. J. Drake; 1 female from Natchitoches Parish, La., August 16, 1928, A. M. James; and 2 males from Prattville, Ala., July 21, 1930, P. W. Oman. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 43992); paratypes in the collection of the University of Kansas.

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AGALLIA QUADRIPUNCTATA (Provancher)

(Fig. 8, D, E, F; fig. 16, A; pl. 2, B)

Described by Provancher (*30, p. 376*) in 1872 as *Bythoscopus quadripunctatus*. Van Duzee (*39, p. 301*) in 1892 described the nymphs as *Ulopa canadensis*. A robust, brown species with a pair of black spots on the vertex and pronotum. Length 4 mm, width 1.5 mm.

Color.—Ground color typically light brown but varying from yellowish brown to fuscous. Frontal sutures, apex of clypeus, and antennal pits infuscated; sides of frons and vertex next the eyes dark. Front margin of vertex with two obliquely converging black spots. Anterior margin of pronotum sometimes dark, the pair of black spots on pronotum near posterior margin and slightly farther apart than those on the vertex. Pronotal markings often obscure. Elytra uniformly light brown, veins pale.

Structure.—Robust. Vertex very short, as long next the eyes as medially. Pronotum short, three times as long as vertex, posterior margin slightly concave, lateral margins very short. Elytra broad, a second cross vein usually present between first and second sectors, making three anteapical cells.

External genitalia.—Last ventral segment of female about twice as long as preceding segment, lateral angles rounding, posterior margin truncate and slightly reflexed caudad of a transverse constricted portion in the posterior one half of the segment. Male valve large, slightly produced medially, lateral margins inclosing base of plates. Plates small and pointed, together forming an acute triangle, lateral margins slightly convex, tips equaling pygofer in length. Pygofer in lateral view with posterior margin broadly rounded.

Internal male genitalia.—Aedeagus long and slender, curving slightly ventrad and unforked at tip.

Provancher described *quadripunctata* from Canada, and the type is in the Museum of Public Instruction in Quebec. The species is common throughout the northeastern portion of the United States and eastern Canada, and is found commonly as far south as northern Alabama, Georgia, and Louisiana, and as far west as eastern Kansas and Nebraska. Farther north the species occurs in small numbers to the Pacific coast, there being specimens at hand from South Dakota, Colorado, Utah, Idaho, Oregon, California, Vancouver, and British Columbia. In the eastern part of the United States the writer has found it most abundant in moist, shaded situations, especially violet patches, in association with *Nionia palmeri* (Van D.). Males of the species are very rarely encountered in collections, but the writer has examined a considerable series through the courtesy of C. E. Olsen, of the American Museum of Natural History.

AGALLIA QUADRIPUNCTATA subsp. EXCAVATA n. subsp.

(Fig. 7, D, E, F; fig. 16, B)

Smaller than the species but with the male genital characters similar to those of typical *quadripunctata* and the female genital segment slightly, roundly excavated. Length of male 3.5 mm, of female 3.75 mm.

Color.—Typically light yellowish brown, lighter and with less golden-brown tinge than *A. constricta*, often darker, especially the males. A pair of black spots on the anterior margin of the vertex, slightly farther apart than the ocelli, and another pair caudad of these on the hind margin of the pronotum. Dark specimens have a median line on pronotum and vertex and areas on anterior margin of pronotum approaching fuscous. Elytra light yellowish brown to subhyaline.

Structure.—Males of general aspect of *A. constricta*, females more robust and intermediate between *A. constricta* and *A. quadripunctata*. Vertex of uniform length, eyes swollen beyond normal curve of vertex. Lateral margins of pronotum obscure. Elytra usually lacking second cross vein between sectors.

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External genitalia.—Last ventral segment of female about twice as long as preceding segment, lateral angles well produced and broadly rounded, posterior margin with a broad but shallow and rounded excavation. Male valve large, twice as wide as long. Plates small and pointed, tapering gradually from a rather broad base, together somewhat rounded at the tips, very similar to those of typical *quadripunctata*. Pygofer slightly exceeding plates.

Internal male genitalia.—Very similar in general structure to typical *quadripunctata*, but all parts somewhat smaller.

Differs from typical *quadripunctata* in the size, female genitalia, and in the absence, usually, of the second cross vein of the elytra. This form has been given subspecific rank because specimens from Colorado seem to furnish the necessary intergradation to typical *quadripunctata*, which does not occur in the same region.

Holotype male from Tucson, Ariz., April 11, 1896, R. E. Kunze, C. F. Baker collection (1856). Allotype female from Tucson, Ariz., April 30, 1896, R. E. Kunze, C. F. Baker collection (2073). Paratypes, numerous examples of both sexes from Tucson, Huachuca Mountains, Granite Dell, Santa Catalina Mountains, Chiricahua Mountains, and Long Valley, Ariz.; Belen, Taos, Jemez Springs, and Albuquerque, N.Mex. There are also specimens at hand from Mexico and southern Colorado. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 43993); paratypes in the collections of the University of Kansas and E. D. Ball.

AGALLIA BIDACTYLATA n.sp.

(Fig. 7, J, K, L; fig. 16, C, D)

General aspect of *quadripunctata* subsp. *excavata*, but larger and the female genital segment with three processes. Length 3.75–4.25 mm.

Color.—General color and markings as in subsp. *excavata* of *quadripunctata*, with which it has probably been confused. General ground color varying from light brown to dark brown, spots on vertex above ocelli and near posterior margin of pronotum piceous, other markings varying from golden brown to fuscous. Elytra brownish subhyaline, veins bluish white.

Structure.—Robust, vertex short and of uniform length, pronotum short and elytra broad with second cross vein between sectors absent.

External genitalia.—Last ventral segment of female longer than preceding segment, hind margin with a small, bluntly bifid median process and on each side of this a slender, tapering, fingerlike process which is curved slightly toward the median line. Male valve rather short and broad, posterior margin truncate. Plates almost parallel sided, appearing somewhat tubular, outer margins longer than inner margins, apices bluntly rounded and somewhat oblique, not equaling the heavy pygofer in length.

Internal male genitalia.—Aedeagus rather short and stout, in lateral view sinuately curved, in dorsal view broad, the tip terminating in a pair of forcepslike processes with lateral margins serrate.

The quite distinct genital characters of both sexes will at once separate this species from all other described forms in the genus.

Holotype male from Santa Rita Mountains, Ariz., July 13, 1930, E. D. Ball. Allotype female taken by Doctor Ball in the same locality, July 12, 1931. Paratypes, 1 male from Tucson, Ariz., September 1, 1929; 1 female with the same data as the allotype; and 1 male from the Santa Rita Mountains, Ariz., July 17, 1932, R. H. Beamer. Holotype and allotype in the collection of E. D. Ball; paratypes in the United States National Museum collection (catalog no. 43994) and the collection of the University of Kansas.

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AGALLIA INGENS n. sp.

(Fig. 7, G, H, I; fig. 16, E, F)

Resembling *A. producta* but larger, darker, and more robust. Length of male 4 mm, of female 4.25 mm.

Color.—Light brownish, heavily marked with dark brown and fuscous. Face variously embrowned with distinct fuscous marks as follows: Tips of clypeus and genae, frontal sutures, sides of frons, antennal pits, spots above ocelli, and inverted Y on vertex. Pronotum with fuscous marks as follows: A median line, broad lateral submargins, anterior margin except next median line, and two large spots posteriorly. Scutellum with basal angles and median stripe brown to fuscous. Elytra uniformly brown to fuscous with veins distinct and light.

Structure.—Very robust, in form somewhat like the South American *sara* Baker (*major* of Osborn), but smaller. Vertex short, of uniform length, and smoothly rounded. Pronotum short, hind margin nearly straight, lateral margins more pronounced than is common in the group. Elytra long and broad, venation as in *A. constricta.*

External genitalia.—Last ventral segment of female with posterior margin triangularly produced from lateral angles, at the base of the triangle sharply constricted across entire width except medially, lateral margins appearing tucked under base. Male valve transverse, collarlike, one half as long as width of posterior margin, which is truncate. Plates short, broad on basal one third, then abruptly narrowed, tips together bluntly rounding, and exceeding pygofer, somewhat similar in shape to those of *A. albidula*, but larger.

Internal male genitalia.—Aedeagus in lateral view broad basally, becoming tubular apically and with the tip turned abruptly upward. A pair of long spines arise from the aedeagus just anterior to the curve upward and extend caudally and laterally, exceeding the upturned tip in length. Posterior margins of pygofer slightly produced ventrally.

The genital characters, especially those of the aedeagus, will separate this from any other known species.

Holotype male and allotype female from Frijoles, Canal Zone, October 23, 1918, Dietz and Zetek (G-291). Paratypes, 1 male from Juan Mina plantation, Canal Zone, July 13, 1918, Dietz and Zetek; 1 female, same locality and collectors, August 24, 1918; 1 male and 1 female from Chagres River, Flat Rock plantation, Canal Zone, August 24, 1918, Dietz and Zetek; and 1 male from Suiza, Turrialba, Costa Rica, P. Schild. Holotype, allotype, and paratypes in the United States National Museum Collection (catalog no. 43995); one paratype in the collection of E. W. Davis.

AGALLIA BARRETTI Ball

(Fig. 7, M, N, O; fig. 16, G, H; pl. 4, I)

Described by Ball (*4, p. 128*) in 1900. Black with reddish-brown markings, or rarely nearly wholly reddish brown. Length of male 3–3.5 mm, of female 3.5–4 mm.

Color.—Usually wholly piceous except for four small reddish-brown to yellowish spots on the posterior margin of the vertex and various pale spots on the front and on the veins of the elytra. Dark extremes have no light marks at all. Some specimens have pale rings around the ocelli which may be fused dorsally with the spots on the vertex, while extremely light examples are wholly reddish brown with only mottled fuscous marks on the front, pronotum, and scutellum.

Structure.—Robust, approaching the genus *Aceratagallia* in general shape but with the pronotum granulated and faintly transversely furrowed instead of coarsely transversely striated. Anterior margin of vertex not evenly rounded but straight or appearing slightly concave laterally, posterior margin broadly rounded, length of vertex between eyes and middle thus being less than the length medially or next the eyes. Posterior margin of pronotum shallowly concave. Elytra broad but strongly exceeding abdomen; second cross vein present.

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External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, posterior margin broadly, roundly produced, often appearing slightly notched medially. Male valve moderately long, transverse, hind margin bisinuate, longer medially than laterally. Plates rather slender, sharply tapering to pointed apices, together triangular and equaling pygofer in length; lateral margins straight or faintly concave.

Internal male genitalia.—Aedeagus in lateral view heavy and curved sharply upward, the tip bearing a pair of downward projecting spines on each side. Styles ending in two points caudally, typical of the genus *Agallia.*

Original description based on two females from Cuernavaca, Mexico. Specimens at hand are from Durango, Mexico City, and the State of Guerrero, Mexico; and Pima and Mescal Counties, Ariz. The species probably occurs throughout the intervening territory and reaches its northern limits in southern Arizona. As Ball states in his description, this species is somewhat intermediate in general character between the *quadripunctata* and *sanguinolenta* groups, but the form of the styles and the character of the pronotum clearly place it in the former group, rather than the latter, to which it was referred by Ball. Type in the collection of E. D. Ball.

AGALLIA NIGRICANS Uhler

(Fig. 6, D, E, F; fig. 16, I; pl. 4, J)

Described by Uhler (*37, p. 82*) in 1895. A small, dark, robust species with light marks on vertex and scutellum and sometimes on pronotum. Length 2.5–2.75 mm.

Color.—Mostly black to fuscous. Light yellowish marks on genae, outer margins of lora, and frons. A spot below each ocellus and an irregular ring around the large piceous spots on anterior margin of vertex above ocelli yellowish, as are two small spots midway on the lateral margins of the scutellum. Pronotum occasionally with a small pair of oblique yellowish spots on each side centrally and a larger pair behind these on the posterior margin. Elytra dark, veins occasionally pale for short distances, the most constant mark being on the first sector of the corium, just before it branches. Hind wings black subhyaline, veins dark.

Structure.—Short and broad, vertex of uniform length or slightly longer medially. Posterior margin of pronotum slightly concave, elytra with costal margins strongly curved, venation often obscure, second cross vein present.

External genitalia.—Last ventral segment of female long and broad; lateral margins turned up, lateral angles well produced and rounded, posterior margin truncate but appearing slightly concave because of the curvature of the segment. Male valve transverse, short. Plates united on basal one half, twice as long as pygofer, tapering gradually from a rather narrow base to somewhat pointed apices, lateral margins curved upward, posterior one half of plates bearing coarse setae, an unusual character in this group.

Internal male genitalia.—Aedeagus in lateral view consisting of two sharp, caudally projecting spines, the ventral one shorter and nearly straight, the dorsal one, which carries the ejaculatory duct, longer and curved a little downward. Posterior margins of pygofer curved mesad and produced into long, stout spines which curve upward and then project directly caudad.

This interesting little species may easily be distinguished by its dark color and the unique genital characters.

Described from St. Vincent Island. Specimens at hand are from St. Vincent, a short series from Trinidad (Morrison collection), and a single male from Panama. Cotypes in the United States National Museum collection (catalog no. 10219).

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AGALLIA HYSTRICULA n. sp.

(Fig. 7, P, Q; fig. 16, J)

Closely allied to *A. nigricans* but much larger and more robust and with the distal portion of the aedeagus simple, without a spine basally. Length of male 3 mm.

Color.—Face brown, heavily marked with black. Vertex black with brown markings as follows: Posterior margin; U-shaped marks around ocelli, oblique arms connecting these with the hind margin, and a narrow median line. Pronotum mostly black; 2 triangular white spots each side of center, a pair of small brown spots anteriorly, and 3 brownish spots on each side laterally. Scutellum black, except posterior one half of lateral margins whitish. Elytra basally black with brown veins, tips fuscous, discal portions hyaline with fuscous veins; 2 white spots along commissural line, 2 faint ones basally on the claval veins, 1 on the corium at the forking of the first sector, and 1 on the claval suture. Hind wings hyaline, veins dark.

Structure.—Very robust, vertex slightly swollen medially, pronotum slightly concave behind. Elytra broad, second cross vein between sectors present.

External genitalia.—Male valve broad, rather short, hind margin convex. Plates long, united and broad basally, tapering to bluntly rounded tips, beset with coarse setae laterally, in all very similar to those of *A. nigricans* but proportionately larger. Lateral margins of plates turned up.

Internal male genitalia.—Aedeagus long and slender distally, in lateral view strongly curved, tip extending directly caudad. Hind margins of pygofer produced into long, slender pieces which extend caudally and curve upward, their tips equaling the plates in length.

The size and male genital characters serve to distinguish this species from Uhler's *nigricans*, which it closely resembles. Described from a single male.

Holotype male from San Jose, Costa Rica, March 1928, J. F. Tristan. Type in the United States National Museum collection (catalog no. 43996).

The genus ACERATAGALLIA Kirkaldy

Vertex short, usually distinctly longer medially than next the eyes, posterior margin broadly rounded and not noticeably produced behind the eyes. Markings of vertex, when present, consisting of a pair of oval spots above the ocelli, paired median stripes, and dark areas next the eyes. Markings occasionally entirely missing. Pronotum with lateral margins very short, posterior margin usually slightly concave, the whole pronotal surface transversely striated or rugulose. Pronotal markings, when present, consisting of five irregular, longitudinal stripes. Scutellum usually with a pair of dark triangles basally. Elytra equaling or exceeding tip of abdomen in length, venation usually distinct, with either 4 or 5 apical and 2 or 3 anteapical cells; markings, when present, of broken patches of brownish, fuscous, and black. Internal male genitalia with styles of various shapes but always unforked; aedeagus simple, strongly bent, spines of tenth segment long and unforked. Nymphs without processes on the vertex.

Type of the genus, *Bythoscopus sanguinolentus* Provancher.

The genus is apparently limited in distribution to North America. Osborn's citation (*23, p. 18*) of the European *venosa* (Fall) to this genus is erroneous, for *venosa*, although it possesses the transversely striated pronotum, has the styles of the male genitalia forked and therefore cannot be a true *Aceratagallia*. There are numerous South

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American species which have a superficial resemblance to this genus; but, of those examined by the writer, none can be placed in the genus *Aceratagallia* as limited above. The species treated in this bulletin may be roughly divided into two groups. The first group includes those forms which have the female genital segment similar in general structure to that of *sanguinolenta* and also have the aedeagus of the male of the same general type as in that species. This group includes the majority of the species in the genus, but the limits are somewhat indefinite. The second and more distinct group is characterized by the distinctly 4-lobed posterior margin of the female genital segment and by the V-shaped aedeagus of the male. At present only six species are known to belong in this group, of which *bigeloviae* is a typical example. *A. uhleri* and *A. gillettei* do not properly belong in either of the above-named groups but in the character of the aedeagus seem to occupy a somewhat intermediate position.

Key to the species of ACERATAGALLIA [2]

1 Aedeagus of male rather V-shaped in lateral view (fig. 18, K). Posterior margin of female genital segment with 3 incisions of almost equal depth and the segment thus distinctly 4-lobed (fig. 12, E) 2
Aedeagus not V-shaped in lateral view (fig. 17, A, C, U). Posterior margin of female segment not as above 7

2 (1) Male plates in lateral view strongly arcuated, in ventral view with apices bluntly rounded and diverging (fig. 12, R) ..... *aplopappi*, p. 67.
Male plates arcuated but little, if any, apices closely appressed and turned upward 3

3 (2) Outer point of style of male genitalia equal to or but little longer than inner point (fig. 18, V, X) 4
Outer point of style of male genitalia long and much produced, several times as long as inner point, which is scarcely produced (fig. 18, R) 5

4 (3) Posterior margin of style convexly rounded; shank of style nearly straight, ventral tooth large. Species large and robust, length 3.25–3.75 mm ..... *dondia*, p. 68.
Posterior margin of style nearly truncate, slightly sinuate, shank of style sinuately curved, ventral tooth small. Species small and relatively slender, length not over 3.25 mm ..... *lobata*, p. 67.

5 (3) Posterior margin of style evenly rounded from inner to outer point, the latter rather blunt ..... *vastitatis*, p. 69.
Posterior margin of style not evenly rounded from inner to outer point, outer point very sharp 6

6 (5) Length 2.5–2.75 mm. Species usually well marked with black or fuscous ..... *bigeloviae*, p. 66.
Length 3–3.25 mm. Species at most marked with tiny spots on vertex above ocelli, these often missing ..... *tergata*, p. 69.

7 (1) Male plates truncate apically, about as long as basal width; style broad and flat, subtruncate (fig. 18, N). Female genital segment with a flaring V-shaped notch in the posterior margin (fig. 12, B) *uhleri*, p. 62.
Species not as above 8

8 (7) Male plates comparatively slender, lateral margins curved upward and with a small notch on each side near the apex (fig. 18, G); style extremely broad apically (fig. 18, H). Female genital segment broadly notched with the sides of the notch sinuate or slightly toothed (fig. 12, H) ..... *gillettei*, p. 66.
Species not as above 9

9 (8) Style of male genitalia strongly curved laterally, either flat or twisted and keeled (fig. 18, B, D, F) 10
Style of male genitalia not strongly curved 12

[2] Aside from the use in group segregation and in the differentiation of *uhleri* and *gillettei*, the characters of the female sex are not sufficiently definitive for use in the key.

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10 (9) Style twisted and somewhat keeled, serrations along inner margin rather fine (fig. 18, B, D) 11
Style flat, not twisted or keeled, serrations along inner margin coarse (fig. 18, F) ..... *curvata*, p. 61.
11 (10) Length 3.25–3.75 mm. Species comparatively slender. Distribution west of Rocky Mountains ..... *californica*, p. 59.
Length 2.5–3 mm. Species robust. Distribution east of Rocky Mountains ..... *vulgaris*, p. 60.
12 (9) Posterior portion of style boot shaped, the outer point, or toe, sharp (fig. 17, Z) 13
Posterior portion of style not boot shaped (fig. 17, T, V, X) 26
13 (12) Male plates long, length clearly exceeding greatest width, lateral margins straight or nearly so, apices thin and bent slightly upward 14
Male plates short, length less than or barely equaling greatest width, or, if longer, lateral margins convex or concave 15
14 (13) Style of male genitalia without a ventral tooth, posterior margin convex, serrations on inner margin fine and regular (fig. 17, N) *pallida*, p. 53.
Style of male genitalia with a ventral tooth anterior to middle of posterior one half, posterior margin slightly concave, serrations on inner margin coarse and irregular (fig. 17, G, H) ..... *abrupta*, p. 52.
15 (13) Male plates short and stubby, somewhat lyrate, length about equal to greatest width, lateral margins concave, tips bent upward (fig. 10, F) ..... *obscura*, p. 63.
Male plates never with lateral margins concave, not at all lyrate 16
16 (15) Style of male genitalia without ventral tooth 17
Ventral tooth always present, although frequently small and indistinct 22
17 (16) Male plates shorter than basal width, lateral margins straight, apices truncate. Species very robust ..... *robusta*, p. 48.
Male plates equal to or longer than basal width, or, if short, with lateral margins convex. Species not exceedingly robust 18
18 (17) Species very small, 2.5 mm or less in length. Style of male genitalia with shank over one half as wide as distance between inner and outer points, outer point short (fig. 16, V) ..... *nana*, p. 55.
Species larger, at least 2.5 mm long, usually much longer. Style of male genitalia with shank much less than one half as wide as distance between inner and outer points, outer point well produced 19
19 (18) Male plates with lateral margins broadly convex, length greater than greatest width 20
Male plates with lateral margins straight or nearly so, length less than or equaling greatest width 21
20 (19) Species distinctly fuscous marked, length 2.75–3.25 mm *sanguinolenta*, p. 58.
Species dirty whitish, unmarked except for spots on vertex and scutellum, length 2.65–3 mm ..... *cinerea*, p. 55.
21 (19) Length of male plates equal to basal width, species robust, marked with brown and fuscous ..... *humilis*, p. 49.
Length of male plates greater than basal width, species comparatively slender, pale yellowish, usually with few marks *nanella*, p. 56.
22 (16) Species heavily marked with fuscous and black 24
Species pale dirty whitish, unmarked except for spots on vertex and scutellum, the latter often absent 23
23 (22) Ventral tooth of style large, situated anterior to the middle of the posterior one half; second cross vein between sectors of elytra nearly always absent, male plates resembling those of *sanguinolenta* (fig. 8, R) ..... *inconspicua*, p. 53.
Ventral tooth of style small, situated posteriorly; second cross vein between sectors of elytra nearly always present, male plates much shorter (fig. 8, O) ..... *helveola*, p. 54.
24 (22) Male plates relatively small, lateral margins nearly straight and converging little, if any (fig. 11, U). Style slender (fig. 18, I) *fuscoscripta*, p. 61
Male plates either longer or wider, lateral margins slightly convex and converging posteriorly. Style relatively stout 25

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25 (24) Male plates with apices truncate, angles between lateral and posterior margins distinct (fig. 9, I) ---------- *accola*, p. 57.
Male plates not truncate apically, but rounded rather smoothly from lateral to posterior margins (fig. 10, R) ---- *poudris*, p. 57.
26 (12) Style of male genitalia with width at apex (distance between inner and outer points) less than width of shank at middle; points of style not produced (fig. 16, P) ---------- *curta*, p. 64.
Style of male genitalia with distance between inner and outer points greater than width of shank at middle, points of style well produced ---------- 27
27 (26) Male plates long, slender, and lyrate (fig. 11, I); tips not turned upward ---------- *lyrata*, p. 65.
Male plates not at all lyrate, or, if slightly so, with tips bent abruptly upward ---------- 28
28 (27) Male plates large, much longer than basal width and width one third the distance from apex almost equal to basal width, lateral margins slightly concave (fig. 10, U). Style with ventral tooth missing ---------- *sordida*, p. 58.
Male plates not as above, lateral margins usually convex or straight; if concave then narrow apically and with the tips bent abruptly upward. Ventral tooth of style present or absent ---------- 29
29 (28) Style of male genitalia without ventral tooth ---------- 33
Ventral tooth of style always present, sometimes small and obscure ---------- 30
30 (29) Male plates somewhat lyrate, lateral margins concave, tips bent abruptly upward (fig. 10, F). Ventral tooth of style small *obscura*, p. 63.
Male plates not at all lyrate, lateral margins straight or nearly so ---------- 31
31 (30) Tips of male plates thickened and bent abruptly upward. Ventral tooth of style large and situated near the apex of the style (fig. 17, V) ---------- *arida*, p. 64.
Tips of male plates not thickened, although sometimes bent slightly upward. Ventral tooth of style somewhat obscure and situated in the middle or anterior to the middle of the posterior portion ---------- 32
32 (31) Species large, 3.25 mm or more in length; ventral tooth of style anterior to middle of posterior portion ---------- *abrupta*, p. 52.
Species small, 3 mm or less in length; ventral tooth of style in middle of posterior portion ---------- *nitidula*, p. 52.
33 (29) Distance between inner and outer points of style about twice the width of shank at narrowest point ---------- 34
Distance between inner and outer points of style not over 1½ times width of shank at narrowest point ---------- 35
34 (33) Posterior margin of style evenly convexly rounded, inner margin regularly serrate (fig. 17, N). Male plates relatively slender (fig. 9, F) ---------- *pallida*, p. 53.
Posterior margin of style sinuate, partly concave and partly convex, inner margin irregularly serrate (fig. 16, R). Male plates stouter (fig. 8, C) ---------- *texana*, p. 51.
35 (33) Outer point of style distinctly spurlike and situated distinctly basad of inner point, inner point forming an oblique angle with posterior margin (fig. 16, X) ---------- *calcaris*, p. 50.
Outer point of style not spurlike, situated about even with inner point, inner point forming a right angle with posterior margin (fig. 16, L) ---------- *compacta*, p. 51.

ACERATAGALLIA ROBUSTA n. sp.

(Fig. 8, J, K, L; fig. 16, S, T)

Pale and very robust, the spots on the vertex very small. Length of male 2.5 mm, of female 2.75–3 mm.

Color.—General ground color yellowish cinereous. Face creamy with frontal sutures and transverse bars laterally on frons brownish. Ocelli pink. Vertex with small black spots above ocelli, a faint longitudinal brownish stripe each side of median line, and a faint brownish area next each eye. Markings of pronotum very faint brown or obsolete. Elytra faint yellowish brown to subhyaline, marked with whitish on clavus and basally on corium, veins mostly

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faintly brownish. Outer claval vein fuscous for a short distance on disk of clavus, the outer sector of corium fuscous basally and again even with the fuscous mark of the claval vein, the inner sector also lightly fuscous at this point. Male plates with apices and inner margins apically, black.

Structure.—Very robust, vertex distinctly longer medially than next the eyes, median length nearly one half the length of the pronotum. Elytra short and broad, barely exceeding the tip of the abdomen in some females, second cross vein between sectors present or absent.

External genitalia.—Last ventral segment of female twice as long as preceding segment, posterior margin nearly truncate but slightly produced and notched medially. Male valve very short and transverse, posterior margin truncate. Plates short and broad, broader basally than apically, apices subtruncate, lateral margins nearly straight.

Internal male genitalia.—Posterior portion of style stout, outer point produced and sharp, inner point short, inner margin coarsely serrate, apex truncate. Style with a faint indication of a ventral tooth near the apex. Aedeagus slender, tip pointed.

The small size, robust form, and male genitalia are distinctive characters.

Holotype male from Las Vegas, Nev., July 6, 1929, David E. Fox. Allotype female, same locality and collector, May 6, 1929. Paratypes, 51 specimens of both sexes from Las Vegas, Overton, and Glendale, Nev., collected in May and July 1929 by David E. Fox; from Phoenix and Granite Dell, Ariz., collected in 1929 and 1930 by E. D. Ball; and from Baboquivari Mountains, Ariz., collected July 19, 1932, by R. H. Beamer. The entire series from Nevada was taken on *Sphaeralcea munroana*, evidently the normal host plant, at least in southern Nevada. Ball's specimens were also on *Sphaeralcea*. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44004); paratypes in the collections of E. W. Davis, E. D. Ball, and the University of Kansas.

ACERATAGALLIA HUMILIS n. sp.

(Fig. 9, M, N, O; fig. 17, A, B)

Smaller and more robust than *sanguinolenta*, with male plates similar to those of *A. robusta*. Length of male 2.75–3 mm, of female 3–3.25 mm.

Color.—Usually similar to pale examples of *A. vulgaris* but apparently never so pale as the extreme forms of that species, usually well marked with brown in the females and fuscous in the males. Spots on vertex above ocelli small and black, median markings of vertex and pronotum usually the most distinct.

Structure.—Short and rather broad. Males less robust than females. Vertex moderately produced, somewhat tumid. Elytra with second cross vein usually present.

External genitalia.—Last ventral segment of female similar to that of *A. sanguinolenta*. Male plates resembling those of *A. robusta*, but longer in proportion to the width. Lateral margins nearly straight, apices truncate.

Internal male genitalia.—Posterior portion of style rather slender, outer point produced more than that of *A. accola*, posterior margin not sinuate as in *A. robusta*, inner margin irregularly serrate, ventral tooth obscure.

This species is most likely to be confused with *A. vulgaris*, which it resembles in general appearance. However, the characters of the male genitalia are very distinct, so there should be no difficulty in separating the two species. The writer collected both nymphs and adults of this species from weeds growing in dry, open places where the soil is rather sandy. The host plant is not known.

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Holotype male, allotype female, and over 50 paratypes taken by the writer at Garnett, Kans., June 20, 1931. Other paratypes collected on the sand dunes at Medora, Kans., June 21, by D. A. Wilbur. There are also specimens at hand from Gallion and Marion Junction, Ala. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44649); paratypes in the collections of the University of Kansas, D. A. Wilbur, and E. D. Ball.

ACERATAGALLIA CALCARIS n.sp.

(Fig. 9, J, K, L; fig. 16, W, X; pl. 3, C)

Resembling *A. uhleri* but smaller, the female genital segment not deeply notched. Length of male 2.75–3 mm, of female 3–3.25 mm.

Color.—Brownish cinereous, marked with brown or fuscous; often pale. Front light yellowish with frontal sutures, median portion of clypeus, and broken transverse bars on sides of frons light brown. Arcs separating vertex and frons and the vertex next the eyes brownish. Spots on vertex above ocelli black, and stripes each side of median line faint brownish. Pronotum with anterior submargin and three pairs of indistinct longitudinal stripes light brown. Black basal triangles on scutellum small. Elytra subhyaline, veins mostly fuscous. Tips of male plates black.

Structure.—Smaller than *A. uhleri*, less robust than *A. sanguinolenta*. Vertex moderately produced, very slightly longer medially than next the eyes. Pronotum short, posterior margin slightly concave. Elytra long, second cross vein between sectors often absent.

External genitalia.—Last ventral segment of female twice as long as preceding segment, lateral margins straight, posterior margin slightly sinuate each side of a faint median notch. Male valve short, transverse, anterior and posterior margins parallel. Plates together slender and tapering, united except at tips, which are closely appressed and together bluntly rounded, equaling pygofer in length. Lateral margins of plates somewhat rounded upward.

Internal male genitalia.—Posterior portion of style slender, almost straight, very similar to that of *A. lyrata*, outer point slender and sharp, situated anterior to apex of style, inner point blunt, inner submargin below serrate. Style without ventral tooth. Aedeagus strongly curved, tip bluntly pointed.

This is another form which has apparently been confused with *A. sanguinolenta*, as it occurs commonly in western Kansas and eastern Colorado and superficially resembles that species. However, aside from the less robust form, this species is easily distinguished from *A. sanguinolenta* by the shape of the style of the internal male genitalia and by the fact that the male plates are more slender and curved upward laterally. It may be distinguished from *A. uhleri* by the smaller size and the characters of the genitalia of both sexes.

Holotype male from Rocky Ford, Colo., August 7, 1912, on sugar beets. Alloytpe female from Rocky Ford, Colo., August 4, 1911, on sugar beets, H. O. Marsh. Paratypes, several specimens of both sexes from the same locality and from Garden City, Finney County, Kans., H. O. Marsh, and Finney County, Kans., August 15, 1924, P. B. Lawson and R. H. Beamer. There are also specimens at hand from various localities in Texas, New Mexico, and Arizona, indicating wide distribution in the arid and semiarid regions of the west. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44007).

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ACERATAGALLIA TEXANA n.sp.

(Fig. 8, A, B, C; fig. 16, Q, R)

Allied to *A. calcaris* n.sp. but more robust, with the male plates longer, broader, and more truncate at the tips. Length 2.75–3 mm.

Color.—Whitish with markings varying from yellowish brown to fuscous. Face pale, seldom marked with brown, occasionally pinkish tinged. Markings of vertex and pronotum, except the two black spots above the ocelli, very pale and indistinct. Black triangles at base of scutellum small or obsolete. Elytra subhyaline, whitish tinged basally, veins basally and on clavus white, remainder dark. Hind wings milky, adding to the whitish appearance of the elytra. Tips of male plates black.

Structure.—Vertex moderately produced, very slightly longer medially than next the eye. Elytra broad but extending well beyond tip of abdomen, second cross vein between sectors either present or absent.

External genitalia.—Last ventral segment of female twice as long as preceding segment, posterior margin slightly notched medially, faintly or not at all sinuate each side of median notch. Male valve rather short and transverse, posterior margin truncate, lateral margins oblique. Plates large, about one half wider basally than at the subtruncate tips, inclosed laterally at base by pygofer and with lateral margins slightly convex. Plates longer than those of *A. compacta* n.sp.

Internal male genitalia.—Posterior portion of style nearly straight, outer point somewhat spinelike and a little longer than in the following species, inner point scarcely produced, inner margins serrate. Ventral tooth of style obsolete. Aedeagus distinctly widened, appearing somewhat flanged, then tapering to a sharp point.

The genital characters of the male and the shape of the rather short vertex will best distinguish this species.

Holotype male, allotype female, and 9 males and 4 female paratypes from Cameron County, Tex., August 3, 1928, R. H. Beamer. Holotype, allotype, and paratypes in the University of Kansas collection; paratypes in the United States National Museum collection (catalog no. 44006).

ACERATAGALLIA COMPACTA n.sp.

(Fig. 10, M, N, O; fig. 16, K, L; pl. 3, E)

Resembling *A. calcaris* but more robust and with the male plates larger and resembling those of *A. texana* n.sp. Length 2.5–2.75 mm.

Color.—General ground color dirty bluish white, almost obscured by the extensive fuscous and brown markings. Face heavily marked with brown, sometimes reddish tinged. Vertex with the two median brown stripes and brown areas next the eyes unusually large and distinct, spots above ocelli large and black. Anterior submargin of pronotum, and three pairs of longitudinal stripes behind this, brownish, the two pairs of stripes laterally often faint. Scutellum marked with black in varying amounts. Elytra subhyaline, but with the black dorsum giving a dark appearance, veins dark, intermittently marked with pale white basally and on clavus. Tips and inner submargins of male plates black.

Structure.—Robust, vertex well produced and tumid, distinctly longer medially than next the eye. Pronotum very short, hind margin truncate. Elytra short and broad, often barely equaling tip of abdomen in length, second cross vein between sectors present.

External genitalia.—Last ventral segment of female about 1½ times as long as preceding segment, hind margin slightly notched medially and faintly sinuate each side between median notch and rounded lateral angles. Male valve short and transverse, posterior margin truncate, lateral margins oblique. Plates rather broad basally, twice as wide as at tips, lateral margins slightly convex. Tips truncate, not equaling pygofer in length. Pygofer inclosing plates laterally at base.

Internal male genitalia.—Posterior portion of style almost straight, outer point small and somewhat spurlike, shorter than in *A. texana*, inner point scarcely

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produced, inner margin serrate. Ventral tooth of style obsolete. Aedeagus slender and strongly curved.

The internal genital characters of this species are similar to those of *A. texana*, but the two may be separated by the differences in size, the degree of production of vertex, and the shape of the aedeagus.

Holotype male and allotype female from San Diego County, Calif., July 4, 1929, P. W. Oman. Paratypes, 4 males and 4 females with the above data; 3 males and 3 females from San Jacinto Mountains, Calif., July 21, 1929, L. D. Anderson; 1 male and 1 female from the San Jacinto Mountains, July 21, 1929, R. H. Beamer; and 1 male from San Diego County, Calif., July 4, 1929, R. H. Beamer. Holotype, allotype, and paratypes in the University of Kansas collection; paratypes in the United States National Museum collection (catalog no. 44005).

ACERATAGALLIA ABRUPTA n. sp.

(Fig. 8, G, H, I; fig. 17, G, H)

Allied to *A. uhleri* (Van D.) but larger and with the male plates longer and more tapering. Length of male 3.25–3.5 mm, of female 3.5–3.75 mm.

Color.—About as in *A. uhleri;* pale yellowish white, seldom infuscated. Head and pronotum unmarked except for the small, round, black spots on the vertex above the ocelli. Black triangular spots at base of scutellum sharply outlined. Elytra subhyaline, veins on clavus and base of corium white, remainder brown. Tips of male plates with narrow black markings.

Structure.—Slightly more robust than *A. curvata*, distinctly larger. Vertex a little longer medially than laterally, pronotum short, posterior margin slightly angularly concave. Elytra broad, second cross vein between sectors nearly always absent; when present, the anteapical cell thus formed usually very short.

External genitalia.—Last ventral segment of female twice as long as the preceding segment, lateral margins straight, lateral angles well produced and rounded, posterior margin notched medially and distinctly sinuate on each side between middle and lateral margins. Male valve short and transverse, anterior and posterior margins parallel. Plates united, except tips which are bent obliquely upward, broad basally, lateral margins straight and converging, tips rather narrow, truncate.

Internal male genitalia.—Posterior portion of style long and nearly straight, outer point moderately produced and sharp, inner point short, sharp, and hooked downward, inner margins serrate. Ventral tooth of style blunt, swollen, rather obscure, and situated anterior to middle of posterior portion. Aedeagus with tip bent abruptly upward.

This species is best distinguished from *A. curvata* by the size and genital characters, which are quite distinct from those of any other forms.

Holotype male, allotype female, and 23 male and 27 female paratypes from Yuma, Ariz., near the Colorado River, June 17, 1915, Harold Morrison. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44009); paratypes in the collections of E. D. Ball and the University of Kansas.

ACERATAGALLIA NITIDULA n. sp.

(Fig. 10, G, H, I; fig. 17, W, X; pl. 3, H)

Apparently allied to *A. abrupta*, but much smaller and with the styles of the internal male genitalia resembling those of *A. lyrata*. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Pale yellow, front often tinged with pink. Spots on vertex above ocelli piceous, elytra with a soiled appearance, veins sometimes faintly brownish, venation rather obscure. Tips and inner margins of male plates black.

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Structure.—Size and form about as in *A. sanguinolenta*, but slightly more robust and vertex a little more tumid. Elytra short, but extending beyond tip of abdomen; second cross vein between sectors absent.

External genitalia.—Last ventral segment of female about twice the length of the preceding segment, hind margin faintly notched medially and slightly sinuate between middle and rounded lateral angles. Male valve short and broad, posterior margin truncate, lateral margins oblique. Plates resembling those of *abrupta*, but smaller and with the tips not bent obliquely upward. Lateral angles slightly sinuate, width of truncate tips about one half that at base.

Internal male genitalia.—Posterior portion of style stout, outer point spurlike and situated even more distant anteriorly from apex than in *A. lyrata*, inner point blunt, inner margins serrate. Ventral tooth of style small and blunt, situated near apex as in *lyrata*. Aedeagus short and curved.

The styles of the internal male genitalia will distinguish this species from all others except *lyrata* and *calcaris*, and it may be easily distinguished from these two by the shape of the male plates.

Holotype male, allotype female, and 6 male and 9 female paratypes from Santa Rita Mountains, Ariz., 5,000–8,000 feet, June, F. H. Snow. Also two male paratypes from the Baboquivari Mountains, Ariz., July 18, 1932, R. H. Beamer. Holotype, allotype, and paratypes in the University of Kansas collection, paratypes in the United States National Museum collection (catalog no 44008).

ACERATAGALLIA PALLIDA n. sp.

(Fig. 9, D, E, F; fig 17, M, N)

Superficially identical with *A. abrupta* but with male plates wider apically. Length 3.25–3.75 mm.

Color.—Pale cinereous, veins of elytra sometimes marked with brown. Black spots on vertex above ocelli small. Basal spots on scutellum brownish fuscous.

Structure.—General form of *abrupta*, but the females slightly less robust. Second cross vein in elytra present.

External genitalia.—Last ventral segment of female as in *abrupta*. Male plates long, lateral margins straight, apices together appearing concave behind. Plates intermediate in character between those of *nitidula* and *abrupta*, broader apically than either, shorter than the latter.

Internal male genitalia.—Posterior portion of style with outer point well produced, inner point obsolete, posterior margin broadly convex, inner margin coarsely and irregularly serrate. Ventral tooth absent.

It is necessary to examine the male genitalia to distinguish this species.

Holotype male and allotype female from St. George, Utah, September 3, 1929, D. E. Fox, collected on *Dicoria canescens*. Paratypes, 7 males and 9 females from St. George, Utah, Glendale, Nev., and Bright Angel and Tucson, Ariz. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44652), paratypes in the collection of E. D. Ball.

ACERATAGALLIA INCONSPICUA (Baker)

(Fig. 8, P, Q, R; fig. 17, K, L; pl. 3, J)

Described by Baker (*2, p. 198*) in 1898 as a variety of *sanguinolenta*. Uniformly pale yellowish white, smaller and more robust than *A. cinerea* or *A. sanguinolenta*. Length 2.5–2.75 mm.

Color.—Pale yellowish white, the front sometimes tinged with pink, the eyes dark and a deep black spot on the vertex above each ocellus. Tips and inner margins of male plates black.

Structure.—Short and robust, the vertex usually distinctly longer medially than next the eyes. Vertex more produced than in *A. fuscoscripta*. Pronotum

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short, hind margin slightly concave. Elytra short but exceeding the tip of the abdomen in length, second cross vein absent, venation obscure.

External genitalia.—Last ventral segment of female very short and broad, longer next the middle than laterally, posterior margin faintly sinuate each side of a faint median notch. Male valve short, posterior margin straight and parallel to anterior margin, lateral margins oblique. Plates resembling those of *A. sanguinolenta* but shorter, tips almost truncate and exceeded by pygofer, which incloses the bases of the plates laterally.

Internal male genitalia.—Posterior portion of style slender, nearly straight, the apex much as in *A. sanguinolenta* but with the outer point less strongly produced, inner margin serrate. Ventral tooth of style large and situated far anteriorly on posterior portion. Aedeagus strongly curved, bluntly pointed.

Although closely related to them, this species may be easily distinguished from the three following species (*helveola, cinerea,* and *nana*) by the more robust form, the absence of the second cross vein in the elytra, the larger male plates, and the larger size and more anterior position of the ventral tooth of the styles of the male genitalia.

Baker described *A. inconspicua* as a variety of *sanguinolenta,* giving as localities Los Angeles, Calif., and Arizona. Ball (*4, p. 128*) placed *inconspicua* as a synonym of *cinerea.* The Baker series includes two very distinct species, both closely related to *A. sanguinolenta,* but neither of them is *cinerea.* Since Baker's description does not differentiate the two species, the name *inconspicua* must be applied to the California specimens. Specimens at hand from Las Vegas, Nev., agree in every respect with the types and indicate a wide range in the arid areas of the West. The Nevada examples, collected by D. E. Fox and received through the kindness of E. W. Davis, of the Salt Lake City beet-leaf-hopper laboratory, were nearly all taken on *Atriplex garrettii,* which may prove to be the host of the species. Cotypes examined. Cotypes in the United States National Museum collection (catalog no. 44011).

ACERATAGALLIA HELVEOLA n. sp.

(Fig. 8, M, N, O; fig. 18, J; pl. 3, I)

Closely allied to, and easily confused with, *A. inconspicua,* but less robust, the female genital segment longer, and the male plates smaller. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Very much like *inconspicua* but with a dirty tinge. Black spots on vertex above ocelli very small, sometimes obsolete, as are the triangles at the base of the scutellum. Tips of male plates faintly dark.

Structure.—Decidedly less robust than *inconspicua,* with a greater difference in the sizes of the sexes. Vertex less produced than that of *inconspicua,* slightly longer medially than next the eye. Pronotum short. Elytra extending well beyond tip of abdomen, second cross vein between sectors present, venation obscure.

External genitalia.—Last ventral segment of female much longer than that of *inconspicua,* otherwise similar. Male valve much like that of *inconspicua* but a little longer. Plates much smaller than in Baker's species, resembling those of *A. fuscoscripta* n. sp.

Internal male genitalia.—Posterior portion of style about as in *inconspicua,* but the inner point slightly hooked and the ventral tooth smaller and situated about midway on the posterior portion.

Aside from the above-mentioned differences, this species is easily and probably best separated from *inconspicua* by the presence of the second cross vein between the sectors of the elytra. From *fuscoscripta* it may be distinguished by the much paler color.

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Holotype male and allotype female from Overton, Nev., June 12, 1929, D. E. Fox. Paratypes, 2 males from the above locality, July 7, 1929, 8 females and 2 males from Las Vegas, Nev., August 22, 1928, E. W. Davis; 1 female from Las Vegas, Nev., July 1, 1928, E. W. Davis; 2 females from Overton, Nev., September 19, 1929, D. E. Fox; 5 females and 1 male from Bakersfield, Calif., July 24, 1929, R. H. Beamer; and 1 male and 1 female from Alpaugh, Calif., June 7, 1915, W. J. Hartung. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44012); paratypes in the collections of the University of Kansas, E. W. Davis, and E. D. Ball.

ACERATAGALLIA CINEREA Osborn and Ball

(Fig. 10, A, B, C; fig. 17, E, F)

Described as *Agallia cinerea* by Osborn and Ball (*28, p. 62*) in 1898. Aspect of *inconspicua* but larger. Length 2.65–3 mm.

Color.—Uniformly dirty yellowish white, unmarked except for a round, black spot on the vertex above each ocellus and the black triangles at the base of the scutellum, part or all of these sometimes obsolete. Face with a pinkish tinge. Male plates black apically and along inner margins.

Structure.—General shape about as in *inconspicua.* Vertex well produced, about one half as long as pronotum. Pronotum very short, posterior margin shallowly concave. Elytra short and broad, sometimes barely exceeding the tip of the abdomen in female, second cross vein usually absent.

External genitalia.—Last ventral segment of female short, about 1½ times as long as preceding segment, lateral angles sharply rounded, posterior margin nearly truncate, notched medially and slightly, sinuately curved each side of median notch. Valve of male short, transverse, posterior margin truncate, lateral margins oblique. Plates similar to those of *sanguinolenta*, quite large, lateral margins convex, narrower apically than basally and apices truncate.

Internal male genitalia.—Posterior portion of style slightly curved near apex, outer point produced and sharp, inner point scarcely produced, inner margin serrate. Style without ventral tooth, the entire structure very similar to that of *sanguinolenta.* Aedeagus slender, tip blunt.

The shape of the apex of the style and the absence of a ventral tooth will distinguish this species from all others except *sanguinolenta*, and from this species it is easily distinguished by the color and smaller size.

The type series of Osborn and Ball was from "Iowa and Colorado." An examination of several specimens of the series convinced the writer that two quite distinct species were included in it, and that, although Iowa was the first locality mentioned, the salient features of the description, especially the characterization of the male plates, undoubtedly apply to the Colorado specimens. Consequently, the Colorado examples are here considered to represent *cinerea*, and the species to which the Iowa specimens belong is named as a new species. Examples of *cinerea* at hand are from western Colorado and Utah, and the species apparently does not occur east of the Rocky Mountains. Cotypes in collection of Iowa State College, Ames, Iowa.

ACERATAGALLIA NANA n.sp.

(Fig. 11, A, B, C; fig. 16, U, V; pl. 3, K)

Small, robust, pale, marked with brown. Length 2.25–2.5 mm.

Color.—General ground color pale yellowish white, face heavily marked with brown. Vertex with a large area next each eye and a distinct stripe each side the median line brown; spots above the ocelli large and black. Pronotum with

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depressed anterior submargin, a pair of longitudinal stripes medially, and indistinct markings laterally, brown. In pale specimens all the dorsal markings except the black spots on the vertex may be faint or obsolete. Elytra subhyaline, often marked with brown basally. Tips, and inner margins of male plates distally, black.

Structure.—Smaller and slightly less robust than *A. inconspicua*, but with vertex proportionately more produced. Pronotum very short, hind margin nearly straight. Elytra short and broad, apices barely equaling tip of abdomen in length. Second cross vein between sectors usually absent.

External genitalia.—Last ventral segment of female short, lateral angles rounded, hind margin almost parallel to anterior margin but slightly notched medially and faintly sinuate each side of median notch. Male valve short and broad, hind margin truncate, lateral margins oblique. Plates resembling those of *A. calcaris* n.sp. but shorter. Lateral margins convex, tips together bluntly rounded.

Internal male genitalia.—Posterior portion of style broad, outer point much less produced than that of *A. sanguinolenta*, inner point forming a right angle, inner margin serrate. Ventral tooth of style obsolete.

This is one of the smallest species in the genus and may be distinguished from other small forms by the unusually large spots on the vertex and by the genital characters of the males.

Holotype male, allotype female, and 16 male and 11 female paratypes from Santa Rita Mountains, Ariz., 5,000–8,000 feet, June, F. H. Snow. Holotype, allotype, and paratypes in the University of Kansas collection; paratypes in the United States National Museum collection (catalog no. 44013).

ACERATAGALLIA NANELLA n. sp.

(Fig. 9, P, Q, R; fig. 17, O, P)

Most closely resembling *A. nana*, but less robust, longer, and with the male plates broader. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Pale yellowish brown, sometimes with a golden tinge, the spots on the vertex above ocelli black but smaller than those on *nana*; otherwise mostly unmarked but sometimes with brownish marks on pronotum and with veins of elytra intermittently brown.

Structure.—General shape of a small *sanguinolenta*, females more robust than males. Elytral venation obscure, second cross vein present or absent.

External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, the median notch in posterior margin deeper than in most species, margin each side of this scarcely sinuate. Male plates short and stubby, wider and less tapered than those of *nana*, apices subtruncate.

Internal male genitalia.—Posterior portion of style relatively slender, resembling that of *sanguinolenta* but with outer point shorter; inner margin irregularly serrate posteriorly. Ventral tooth obsolete.

This is the species from Arizona which Baker (*2, p. 198*) placed under *inconspicua*, but it may be separated from that species by the absence of a ventral tooth on the style and the shape of the male plates. It may be distinguished from *cinerea* by the shape of the male plates and from *nana* by the more elongate form.

Holotype male, allotype female, and 14 paratypes, representing both sexes, from Prescott, Ariz., July 15, 1896, R. E. Kunze, C. F. Baker collection (2123). Other paratypes from Santa Rita Mountains, Ariz., 5,000–8,000 feet, June, F. H. Snow; Patagonia, Ariz., May 21, 1931, Tucson, Ariz., May 26, 1929, and June 21, 1930, E. D. Ball. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44653); paratypes in the collections of the University of Kansas and E. D. Ball.

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ACERATAGALLIA ACCOLA n. sp.

(Fig. 9, G, H, I; fig. 17, I, J)

Apparently heretofore mistaken for *A. sanguinolenta* but much smaller, darker, more robust, and with the male plates shorter. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Similar to *sanguinolenta* but usually appearing darker, actually with more brown and fuscous than *sanguinolenta*. Males much darker than females.

Structure.—Similar to *A. vulgaris* but smaller, vertex rather tumid. Elytra broad and short, barely extending beyond tip of abdomen; second cross vein either present or absent.

External genitalia.—Last ventral segment of female a little longer than preceding segment, a little longer medially than laterally, posterior margin with a small median notch and slightly concavely sinuate each side of this. Male valve short, truncate posteriorly. Plates short, tapering slightly to truncate apices, lateral margin convex.

Internal male genitalia.—Posterior portion of style similar to that of *A. nana* but with outer point a little more produced. Inner margin irregular serrate, ventral tooth blunt and obscure.

The writer has found this to be the most common species of *Aceratagallia* in dry, sandy places in the vicinity of the District of Columbia. Although not yet definitely determined, the host plant is apparently one of the common weeds found in these open fields where the vegetation is rather short.

Holotype male, allotype female, and over 100 paratypes of both sexes collected at Washington, D.C., August 28, 1932, by the writer. Other paratypes collected near the South River, 4 miles south of Annapolis, Md., July 17, 1932, by the writer. There are also specimens at hand from various other localities near Washington, taken mostly in the late summer of 1932. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44654) and in the collections of the University of Kansas and E. D. Ball.

ACERATAGALLIA POUDRIS n. sp.

(Fig. 10, P, Q, R; fig. 17, Q, R)

Resembling *A. accola* but more robust. Length of male 2.25–2.5 mm, of female 2.5–2.75 mm.

Color.—General ground color grayish cinereous, males heavily marked with fuscous. The most distinctive marks are a pair of brownish-fuscous vittae each side of the median line of the vertex and a brown cloud next each eye, these often entirely obsolete in the female. Spots on vertex above ocelli small, elongate, and set somewhat obliquely outward, these also variable in intensity.

Structure.—More robust than *accola*, the vertex more tumid. Elytra broad, sometimes barely exceeding abdomen in length; second cross vein present or absent.

External genitalia.—Last ventral segment of female as in *sanguinolenta*. Male plates very short, lateral margins convex, rounding to posterior margin with scarcely an indication of an angle.

Internal male genitalia.—Posterior portion of style with outer point well produced, similar to *accola* but with shank of style more slender. Serrations along inner margin irregular, ventral tooth small.

The shape of the male plates will distinguish this species.

Holotype, allotype, and numerous paratypes of both sexes from Poudre Canyon, Colo., August, 22, 1925, R. H. Beamer and P. B. Lawson. Holotype, allotype, and paratypes in the collection of the University of Kansas; paratypes in the United States National Museum collection (catalog no. 44655) and the collection of E. D. Ball.

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ACERATAGALLIA SORDIDA n. sp.

(Fig. 10, S, T, U; fig. 16, M, N)

Allied to *A. sanguinolenta* but with male plates larger and female genital segment slightly produced and notched medially. Length 2.75–3 mm.

Color.—Brownish cinereous, marked with fuscous. Frontal sutures, tip of clypeus, and antennal pits black, sides of frons marked with broken transverse bars of fuscous. Arcs on front above frons and vertex next the eyes light fuscous, spots on vertex above ocelli black, and two median stripes on vertex brownish. Pronotum with anterior margin and three pairs of indistinct longitudinal stripes fuscous. Scutellum with triangles at base and median line black. Elytra fuscous to brownish basally, becoming subhyaline apically, veins of clavus and base of corium broadly white, remainder fuscous. Abdomen variously infuscated, tips and inner margins of plates black.

Structure.—More robust than *A. sanguinolenta.* Vertex slightly longer medially than laterally, pronotum short, hind margin nearly straight. Elytra broad, second cross vein between sectors absent.

External genitalia.—Last ventral segment of female short, longer medially than laterally, lateral margins straight, lateral angles rounded, posterior margin notched medially. Male valve large, posterior margin truncate, lateral margins straight, obliquely converging. Plates broad, united on basal two thirds, lateral margins nearly parallel but slightly concave, tips broadly rounded, almost truncate.

Internal male genitalia.—Posterior portion of style rather slender and nearly straight, outer point small and sharp, inner point well produced, stout, and hooked, inner margin serrate. Style without ventral tooth. Aedeagus strongly curved, tips pointed.

Probably heretofore confused with *A. sanguinolenta*, which it closely resembles. The genital characters are, however, quite distinct, especially the shape of the style of the internal male genitalia. Apparently widely distributed in Central America, Mexico, and lower Texas.

Holotype male and allotype female from La Ceiba, Honduras, December 13, 1915, F. J. Dyer. Paratypes of both sexes from La Cieba, Honduras, F. J. Dyer; Vera Cruz, Mexico, H. Th. Heyde (C. F. Baker collection 1785 and 2154); Cuernavaca, Mexico, E. G. Smyth; Brooks, Brazoria, Hidalgo, and Karnes Counties, Tex., R. H. Beamer; Kendall County, Tex., L. D. Beamer; Cameron County Tex., E. I. and Jack Beamer; and Amarillo, Tex., L. D. Anderson. There are also at hand two females from Mitla, Mexico, which undoubtedly belong here. Aside from the customary variation in coloring, this large series is very constant in character. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44010); paratypes in the collections of the University of Kansas and E. D. Ball.

ACERATAGALLIA SANGUINOLENTA (Provancher)

(Fig. 11, D, E, F; fig. 17, Y, Z; pl. 2, K)

Described by Provancher (*30, p. 376*) in 1872 as *Bythoscopus sanguinolentus*. Uhler (*36, p. 359*) described the same species in 1876 as *B. siccifolius*. Light brownish gray, with fuscous markings. Rather robust. Length of male 2.75–3 mm, of female 3–3.25 mm.

Color.—General ground color light brown, the females lighter than the males. Front pale with brown markings as follows: Frontal sutures, antennal pits, broken transverse bars on sides of frons, and arcs between vertex and frons. Vertex with a black spot above each ocellus, a brown patch next each eye, and a

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longitudinal brown stripe each side of the median line, these brown areas connected below with the arcs between the vertex and the frons. Pronotum with anterior depressed submargin irregularly fuscous and three pairs of indistinct longitudinal stripes brownish. Scutellum with basal triangles black and sometimes median portion infuscated. Elytra subhyaline to brownish, veins brown to fuscous, marked with white on the clavus and base of corium. Male plates black on tips and inner submargins.

Structure.—Short and broad, vertex a very little longer medially than next the eye, pronotum slightly concave behind. Elytra broad, rather short, second cross vein between sectors usually present.

External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, lateral angles rounded, posterior margin slightly notched medially and feebly sinuate each side of median notch. Male valve short, transverse, lateral margins oblique, anterior and posterior margins parallel. Plates rather broad and flat, lateral margins convex, narrowing to truncate tips which are slightly exceeded in length by the pygofer. Plates slightly inclosed by pygofer laterally at base.

Internal male genitatia.—Posterior portion of style straight, the apex foot shaped, outer point strongly produced and sharp, inner point obscure, inner margin coarsely serrate. Style without ventral tooth, but with a minute protuberance ventrally near the apex. Aedeagus strongly curved, bluntly pointed.

A. sanguinolenta was described from Canada and is the most abundant and injurious species of *Aceratagallia* in eastern North America. It has a wide distribution, occurring throughout the eastern part of the United States and Canada and west into Arizona and Utah. Although the western specimens differ decidedly in general appearance from the eastern form, no constant structural character of specific significance has been found. Because of this, Uhler's *siccifolius* is considered to be a synonym of this species. Published records of *sanguinolenta* from the Pacific coast are probably erroneous determinations of some of the common species of that region. The injury caused by this species, although extensive, is apparently limited to the feeding, as there has been no evidence of disease transmission. Poos (*29*) obtained only negative results in his attempts to connect this species with diseaselike injury to legumes. Type in the collection of the Museum of Public Instruction at Quebec, Canada.

ACERATAGALLIA CALIFORNICA (Baker)

(Fig. 11, M, N, O; fig. 18, A, B; pl. 2, J)

Described as *Agallia californica* by Baker (*2, p. 199*) in 1898. Resembling *A. lyrata* but smaller, with the male plates truncate. Length of male 3.25–3.5 mm, of female 3.5–3.75 mm.

Color.—Brownish cinereous, with fuscous markings. Front pale, sometimes marked with brown. Vertex next the eyes brownish, with a black spot over each ocellus. Eyes dark, with light borders. A faint brownish stripe each side of median line on vertex and pronotum, obscure anteriorly on pronotum. Pronotum laterally with indications of longitudinal stripes of brown. Scutellum with black triangular spots basally. Elytra as in *A. lyrata.* Tips of male plates black, female genital segment brown medially.

Structure.—Intermediate between *A. uhleri* and *A. lyrata.* Vertex slightly longer medially than laterally, hind margin broadly rounded. Elytra long, second cross vein present.

External genitalia.—Last ventral segment of female longer than preceding segment, posterior margin sinuate each side of a median notch, which is usually shallow but occasionally rather deep. The brownish median portion of the female segment gives the appearance of a deep notch. Male valve short, transverse, and truncate behind. Plates together rectangular, slightly longer than wide, united basally, and with lateral margins at base inclosed by pygofer. Pygofer exceeding plates in length.

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Internal male genitalia.—Posterior portion of style curved laterally and twisted, outer point well produced and sharp, inner point obscure, inner margin serrate on curved portion. Ventral tooth of style blunt. Aedeagus in lateral view symmetrically curved, not abruptly bent near tip.

Described from California and common in the mountains of California and Oregon. The writer has taken this species in large numbers from spruce in the San Jacinto Mountains, Calif., which was apparently doing considerable damage to the trees. Cotypes in the United States National Museum collection (catalog no. 44001).

ACERATAGALLIA VULGARIS n. sp.

(Fig. 11, J, K, L; fig. 18, C, D; pl. 3, F)

Similar to *A. sanguinolenta* but smaller and slightly more robust. Length of male 2.5–2.75 mm, of female 2.75–3 mm.

Color.—Varying from light yellowish brown to dark cinereous. Front pale, sides of frons sometimes with short transverse brown lines; vertex brownish next the eyes and with a faint stripe each side of median line on vertex and pronotum in dark specimens. Spots on vertex above ocelli black, eyes dark. Irregular depressed line near anterior margin of pronotum sometimes dark. Scutellum with two small black triangles basally. Elytra subhyaline, veins brownish. Inner margins of male plates dark.

Structure.—Rather robust. Vertex well produced, longer medially than laterally. Elytra relatively broad, second cross vein between sectors usually absent.

External genitalia.—Last ventral segment of female short, about 1½ times as long as preceding segment, posterior margin nearly truncate but slightly notched medially and faintly sinuate between notch and lateral margin. Male valve broad and very short, often hidden by last segment. Plates together short and broad, width near apex greater than at base and nearly equaling length, length of inner margins of plates exceeding that of outer margins. Pygofer inclosing base of plates laterally and slightly exceeding plates in length.

Internal male genitalia.—Posterior portion of style stout, curved laterally and twisted downward, outer point well produced and sharp, inner point rounded, inner margin serrate on curved portion. Ventral tooth of style stout, slightly hooked.

The peculiar twisted style of the male genitalia will distinguish this species from all others in the genus except *californica*, from which it may be distinguished by the smaller size and more robust form.

This is one of the most common species of *Aceratagallia* in the Mississippi Valley, the eastern part of the United States, and southern Canada, its range extending west into Colorado and Texas. It has long been known as *cinerea* Osborn and Ball because the type series of Osborn and Ball's *cinerea* contained specimens of this species from Iowa. It was treated as *cinerea* by DeLong and Davidson (*12*), and no doubt many eastern records under that name should be placed here, since true *cinerea*, judging from the many examples at hand, does not occur east of the Rocky Mountains.

The writer has taken both nymphs and adults in abundance from the common ragweed, *Ambrosia artemisiaefolia* L., in the vicinity of Washington, D.C. In this locality, at least, this seems to be the normal food plant.

Holotype male, allotype female, and many paratypes of both sexes from Washington, D.C., September 11, 1932, collected on *Ambrosia artemisiaefolia* by the writer. Other paratypes from the same locality and host, August 28, 1932, and from Greenwood County, Kans., August 2, 1923, R. H. Beamer and P. B. Lawson. Holotype, allotype, and paratypes in the United States National Museum collec-

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tion (catalog no. 44002) and in the collections of the University of Kansas and E. D. Ball.

ACERATAGALLIA FUSCOSCRIPTA n.sp.

(Fig. 11, S, T, U; fig. 18, I; pl. 4, L)

Aspect of *A. vulgaris*, with the male plates about as in that species, but the styles of the internal male genitalia closely resembling those of *A. sanguinolenta*. Length of male 2.5–2.75 mm, of female 2.5–3 mm.

Color.—Brownish cinereous. Face pale, sometimes pinkish, antennal pits dark and sides of frons marked with short brown lines. Eyes dark, black spots on vertex above ocelli slightly elongate. Pronotum with faint longitudinal brownish stripes; depressed anterior submargin with a pair of fuscous spots and sometimes a pair of dashes. Basal triangular spots on scutellum deep black. Elytra subhyaline, veins mostly brown but partly whitish basally and on the clavus. Apices of male plates black.

Structure.—Less robust than *vulgaris*, males sometimes slightly more slender than females. Vertex well produced, longer medially than next the eye. Pronotum short, slightly concave behind. Elytra extending well beyond tip of abdomen, quite slender in males, second cross vein between sectors nearly always present.

External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, lateral angles rounded, posterior margin slightly notched medially. Male valve rather short, but longer than that of *vulgaris*, anterior and posterior margins parallel, lateral margins oblique. Plates resembling those of *vulgaris* but with lateral margins convex rather than straight, width at apex not exceeding that at base, and tips more truncate than in that species. Plates nearly equal to pygofer in length.

Internal male genitalia.—Posterior portion of style rather short, outer point strongly produced, inner point obsolete, apical portion about as in *A. sanguinolenta*, inner margin serrate along apical one half. Ventral tooth of style small and obscure. Aedeagus short, tip blunt.

This is apparently the most common species of the genus in the northwestern part of the United States. It might easily be confused with *vulgaris*, but the styles of the internal male genitalia will distinguish these two, whereas it may be distinguished from *A. inconspicua* and *A. sanguinolenta* by the shape of the male plates.

Holotype male and allotype female from Grand Teton National Park, Wyo., August 18, 1931, R. H. Beamer. Paratypes, a great many specimens of both sexes with the data given above and others from Northgate, Colo., August 20, 1931, R. H. Beamer; Bennett, Mont., August 12, 1931, J. O. Nottingham; Burley, Idaho, July 16, 1931, R. H. Beamer; Murtaugh, Idaho, June 21, 1930, D. M. DeLong; and Lylton, British Columbia, August 2, 1931, R. H. Beamer. There are also specimens at hand in small series from other localities in Washington, Oregon, Idaho, Montana, Colorado, and British Columbia. Holotype, allotype, and paratypes in the University of Kansas collection; paratypes in the United States National Museum collection (catalog no. 44003) and the collections of E. W. Davis, E. D. Ball, and D. M. DeLong.

ACERATAGALLIA CURVATA n.sp.

(Fig. 11, P, Q, R; fig. 18, E, F; pl. 3, G)

Pale, rather robust, the female genital segment often shallowly excavated, the male plates broad. Stouter and paler than *A. uhleri*. Length of male 2.75–3 mm, of female 3–3.25 mm.

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Color.—Typically uniformly pale yellowish white, occasionally darker. Front faintly tinged with pink to brown. Spots on vertex above ocelli usually very small, but larger in the dark specimens. Triangular black spots at base of scutellum small, the anterior portion showing through the semitransparent pronotum. Elytra hyaline to whitish, veins obscure or sometimes brownish. Hind wings whitish, veins distinct. Tips of male plates blackish.

Structure.—Robust, but not so much so as *bigeloviae.* Vertex moderately produced, slightly longer medially than laterally. Posterior margin of pronotum nearly straight or slightly angularly concave. Elytra broad and short, sometimes barely exceeding the abdomen in length. Second cross vein between sectors usually present.

External genitalia.—Last ventral segment of female over twice as long as preceding segment, lateral margins straight, lateral angles produced and rounded, posterior margin shallowly, angularly excavated from lateral angles with a small median notch and the sides of the excavation sometimes faintly sinuate. Occasionally the excavation is of sufficient depth to resemble that of *uhleri*, but is normally much shallower. Male valve short, transverse, anterior and posterior margins parallel. Plates broad, broader than those of *A. uhleri*, united except on distal one third, slightly narrowed apically, lateral margins turned upward and exceeding inner margins in length, the tips of the plates thus appearing angularly excavated. Base of plates inclosed by pygofer laterally.

Internal male genitalia.—Posterior portion of style strongly curved laterally but not twisted and more broadly curved than in *californica*, outer point strongly produced and sharp, inner point short, slightly hooked, and sharp; inner margin coarsely serrate. Ventral tooth short and blunt, rather obscure. Aedeagus broadly curved, rather slender.

This species has evidently been confused with *A. uhleri*, as the writer has received from correspondents various specimens so labeled. However, the robust form and male genital characters will at once distinguish it from any other known species. Apparently of considerable importance as a truck-crop pest in California. This is the species treated as *uhleri* from that State by DeLong and Davidson (*12*) in their paper on the species of *Agallia* injurious to economic crops.

Holotype male and allotype female from Ashland, Oreg., September 7, 1897, A. Morse (C. F. Baker collection 2376). Paratypes, large numbers of both sexes from Ashland and Glendale, Oreg.; Tehama, Davis, Florin, Shasta County, Fresno, Chico, Bakersfield, El Centro, Santa Cruz, Santa Margarita, Lemoncove, Merced, Greenfield, Lodi, Tulare, Turlock, Salida, Hayward, and Sacramento, Calif., and Pintura, Utah. There are also specimens at hand from southern Nevada. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44000); paratypes in the collection of D. M. DeLong, Herbert Osborn, E. D. Ball, and the University of Kansas.

ACERATAGALLIA UHLERI (Van Duzee)

(Fig. 12, A, B, C; fig. 18, M, N; pl. 3, D)

This species was described by Van Duzee (*40, p. 91*) in 1894 as *Agallia uhleri.* More slender than *Aceteragallia sanguinolenta*, with the female genital segment deeply notched posteriorly. Length of male 3.25–3.5 mm, of female 3.5–3.75 mm.

Color.—General ground color brownish cinereous. Front pale yellowish, sides of frons occasionally with numerous short transverse brown lines. Spots on vertex above ocelli round and black. Sometimes vertex and pronotum with a faint grayish longitudinal stripe each side of median line. Irregular impressed line on anterior margin of pronotum usually dark. Scutellum with triangular basal spots black and transverse suture dark. Elytra subhyaline, sometimes fuscous along commissural line, veins dark except for occasional whitish portions basally and on clavi. Apices and inner submargins of male plates narrowly black.

Structure.—Less robust than *A. sanguinolenta*, approaching *A. lyrata* but smaller. Vertex slightly swollen between ocelli, longer medially than laterally,

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posterior margin broadly and evenly rounded. Posterior margin of pronotum slightly concave. Elytra long, with three anteapical cells.

External genitalia.—Last ventral segment of female twice as long as preceding segment, lateral margins straight, lateral angles rounded, hind margin broadly, angularly excavated nearly half way to the base. Male valve rather short, transverse, lateral margins oblique, hind margin truncate. Plates heavy, lateral margins straight, slightly converging, tips truncate. Sides of plates curving slightly upward. Plates about equaling pygofer in length.

Internal male genitalia.—Posterior portion of style broad, tip truncate, outer point slightly produced, inner margin serrate. Ventral tooth of style sharp, very slightly hooked. Tip of aedeagus in lateral view sharply bent upward.

In his description of the species Van Duzee mentions, as localities in which it occurs, Colorado, Arizona, and California. The writer has seen no examples of *A. uhleri* from California, and it seems probable that Van Duzee's specimens from that State were *A. curvata*, a species which resembles *uhleri* closely in male genital characters and sometimes has the female genital segment rather deeply notched. *A. uhleri* is apparently the most common species of the genus in western Kansas and eastern Colorado, and occurs in great numbers on sugar beets, probably doing considerable damage. Its distribution seems to cover primarily the plains region west of the Mississippi, extending west into Utah and Arizona. Types in the collection of Iowa State College, Ames, Iowa. A female cotype from Arizona has been examined through the courtesy of Drake and Knight.

ACERATAGALLIA OBSCURA n. sp.

(Fig. 10, D, E, F; fig. 17, C, D; pl. 3, B)

Pale cinereous, much lighter and more robust than *A. lyrata*. Male plates somewhat lyrate but much shorter and stouter than those of *lyrata*. Length 3.25–3.5 mm.

Color.—Whole insect with a soiled appearance, paler than *lyrata*. Black spots on vertex above ocelli very small, usually slightly oval. Triangular spots on scutellum very small or obsolete, veins of elytra usually pale, occasionally partly brownish. Apices and inner margins of male plates black.

Structure.—About as in *A. arida* n. sp. Vertex moderately produced, slightly longer medially than next the eye. Elytra extending well beyond tip of abdomen, venation obscure, second cross vein between sections usually present.

External genitalia.—Last ventral segment of female about twice as long as preceding segment, lateral angles well produced and bluntly rounded, posterior margin notched medially and faintly sinuate each side of middle. Male valve short, anterior and posterior margins straight. Plates short and stout, extending downward with the tips bent up as are those of *arida* but even shorter and stouter and with the lateral margins concave. Plates not equaling pygofer in length and much shorter and stouter than those of *A. lyrata*.

Internal male genitalia.—Posterior portion of style broad and rather flat, apex obliquely truncate, outer point not greatly produced, inner point hooked downward, inner margin serrate. Ventral tooth of style moderately produced, less prominent than in *A. arida* and situated farther forward. Aedeagus strongly curved near tip.

This species, a truck-crop pest of considerable importance in California, has apparently been confused with *lyrata*, as it was treated as such by DeLong and Davidson, probably because of the somewhat lyrate male plates. True *lyrata* is primarily a mountain form and may be distinguished from this species by the fact that it is more slender and by the unique characters of both external and internal male genitalia.

Holotype male and allotype female from Davis, Calif., May 25, 1912, on sugar beets (*Beta vulgaris*), W. B. Parker. Paratypes, numerous specimens with the above data and many examples of both

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sexes from Grant's Pass, Oreg.; Chico, Ontario, San Jose, Dublin, Lodi, Mount Eden, Davis, Elk Grove, and Greenfield, Calif. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 43998); paratypes in the collections of D. M. DeLong, Herbert Osborn, E. D. Ball, and the University of Kansas.

ACERATAGALLIA ARIDA n. sp.

(Fig. 10, J, K, L; fig. 17, U, V; pl. 3, A)

Allied to *A. lyrata* and *A. obscura*, but with the male plates not at all lyrate. Length 3.25–3.75 mm.

Color.—About as in *A. lyrata* but often pale and with a dirty tinge. Face usually pale, marked with brown; often pinkish. The spots on the vertex over the ocelli comparatively small, sometimes rather elongate. Basal triangles of scutellum usually small, veins of elytra mostly dark.

Structure.—Rather robust. Vertex well produced, distinctly longer medially than next the eyes. Pronotum short, hind margin slightly concave. Elytra moderately long, second cross vein between sectors present.

External genitalia.—Last ventral segment of female about as in *A. sanguinolenta*, posterior margin notched medially and sinuate each side of median notch, lateral angles well produced, bluntly rounded. Male valve very short, sometimes almost covered by preceding abdominal segment, posterior margin truncate. Plates stout and compact, extending a little downward, the tips closely appressed and bent upward. Width at tips a little over one half basal width, tips not equaling pygofer in length. Plates more slender than those of *A. obscura* and with lateral margins straight or nearly so.

Internal male genitalia.—Posterior portion of style rather stout, slightly curved, outer point moderately produced, inner point stout and hooked, inner margin serrate on apical one half. Ventral tooth of style large, situated near apex. Aedeagus short, strongly curved near tip.

This species is probably most closely related to *obscura*, a California form which it resembles very closely. It may be distinguished from that species, however, by the difference in the male plates mentioned above and by the fact that the styles of the internal genitalia are not so broad and have the ventral tooth more pronounced and nearer the apex. Apparently a very common species in the arid region between the Rocky Mountains and the Sierra Nevada Mountains from Texas, Utah, and Colorado north into Montana and Idaho. Part of Carter's references to *sanguinolenta* (*10, p. 54–55*) apply to this species.

Holotype male and allotype female from Fort Collins, Colo., C. F. Baker collection (1811). Paratypes, a great many specimens of both sexes, taken on various dates by numerous collectors, from the following localities: Fort Collins, Steamboat Springs, Paonia, Mancos, Sloss, Grand Junction, and Durango, Colo.; Snowville, Ogden, Elsinore, Garland, Delta, Blue Creek, Logan, Magna, Collinston, Elberta, Provo, Grantsville, Richmond, Brigham, Rosette, Fielding, Richfield, and Monroe, Utah; Willow Creek, Stevensville, and Whitehall, Mont. Specimens at hand from Texas and Idaho also belong here. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 43999); paratypes in the collections of E. W. Davis, E. D. Ball, D. M. DeLong, and the University of Kansas.

ACERATAGALLIA CURTA, n. sp.

(Fig. 9, A, B, C; fig. 16, O, P)

Allied to *A. obscura* in the shape of the male plates, but more robust and paler. Length 3–3.5 mm.

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Color.—Uniform tawny; eyes, spots on vertex above ocelli, and tips of male plates, black. Ocelli pink.

Structure.—Very robust, pronotum short, elytra barely exceeding abdomen in length, second cross vein between sectors of elytra present.

External genitalia.—Last ventral segment of female similar to that of *obscura.* Male plates broader and flatter than those of *obscura*, the apices thick but not bent upward as in that species.

Internal male genitalia.—Posterior portion of style with both points obsolete, narrowing to apex, inner margin irregularly serrate. Ventral tooth short and hooklike. Dorsal spine of tenth segment unusually long and slender.

Usually it is not advisable to describe species in this genus from so few specimens, but the characters of the styles and male plates are so unique that only three males seemed sufficient.

Holotype male and allotype female from Tucson, Ariz., June 21, 1930, E. D. Ball, and 2 male paratypes from Mescal, Ariz., July 28, 1927, R. H. Beamer. Holotype and allotype in E. D. Ball's collection, 1 paratype in the University of Kansas collection, and 1 paratype in the United States National Museum collection (catalog no. 44651).

ACERATAGALLIA LYRATA (Baker)

(Fig. 11, G, H, I; fig. 17, S, T; pl. 4, K)

Described as *Agallia lyrata* by Baker (*2, p. 199*) in 1898. A large species with the male plates slender and lyrate. Length of male 3.5–4 mm, of female 3.5–3.75 mm.

Color.—Grayish brown, marked with fuscous and black. Front pale, faintly tinged with pinkish, frontal sutures and ends of transverse arcs on frons sometimes brown. Ocelli pinkish, vertex brownish laterally, bluish brown medially, spots above ocelli slightly oval and black, obliquely diverging anteriorly. Eyes dark with light margins. An indistinct, double, median stripe of fuscous on vertex and pronotum and two wider ones on each side on the posterior one half of the pronotum; a pair of round black spots in depressions near the anterior margin of pronotum, elongate depressions laterad and caudad of these also occasionally dark. Scutellum with black triangles at base; transverse suture and two spots anterior to transverse suture dark. Elytra subhyaline, narrowly fuscous along commissural line, claval veins white, except median portion of outer vein; veins of corium pale basally, dark beyond fork of first sector. Hind wings clear, veins dark. Abdomen above black, below tawny; male plates bluish, tips and inner margins black.

Structure.—More slender than *A. sanguinolenta*, the female slightly more robust than the male. Vertex distinctly longer medially than laterally, broadly and evenly rounded behind. Posterior margin of pronotum slightly angularly concave. Elytra long, second cross vein present.

External genitalia.—Last ventral segment of female 1½ times as long as preceding segment, lateral angles slightly produced and rounding, posterior margin notched medially and faintly, concavely sinuate on each side between middle and lateral angles. Median notch variable, usually faint but sometimes quite deep. Male valve short, transverse, posterior margin convexly curved. Plates together of greatest width a short distance from base, then narrowing to a slender neck; apices slightly wider than neck, hind margins truncate, slightly shorter than heavy pygofer.

Internal male genitalia.—Posterior portion of style with outer point spurlike and situated anterior to apex of style, inner point blunt, inner submargin serrate below. Ventral tooth of style short and blunt, situated near apex.

Described from California, where it is quite common in the higher mountains. Ball (*4, p. 128*) placed this species as a synonym of *A. peregrinans* (Stål), but the writer agrees with Baker (*3, p. 152*) that Stål's *peregrinans* must surely be a composite species and that the name may apply to a Hawaiian form. The drawing of Stål's type by Madame Ekblom, published by Osborn (*25, pl. 55, fig. 2*), indicates

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that the species belongs in the genus *Agallia* rather than in *Aceratagallia*, and is apparently closely related to several South American species. Berg (*6, p. 276*) refers to Argentinian specimens as *peregrinans*, but these may represent still another species. Specimens of *lyrata* at hand are from California, southern Oregon, southern Nevada, and Utah. Cotypes in the United States National Museum collection (catalog no. 43997).

ACERATAGALLIA GILLETTEI (Osborn and Ball)

(Fig. 12, G, H, I; fig. 18, G, H; pl. 2, L)

Described as *Agallia gillettei* by Osborn and Ball (*28, p. 60*) in 1898. General shape of *A. uhleri* but smaller, with the male plates tubular and the female genital segment broadly, angularly excavated behind. Length of male 2.75–3 mm, of female 3–3.25 mm.

Color.—Light brown, marked with dark brown and fuscous. Front pale, marked with brown on clypeus and sides of frons. Vertex brown next the eyes and with a round fuscous spot above each ocellus on anterior margin. An indistinct brown stripe each side of median line extending across vertex and pronotum. Pronotum with lateral submargins brown and four faint fuscous dots anteriorly. Scutellum with black triangles basally, transverse suture and central spots brown. Elytra subhyaline, veins, except on clavus and base of corium, dark. First two cells of clavus narrowly fuscous along commissural line. Tip of male plates dark.

Structure.—Less robust than *A. sanguinolenta*. Vertex very slightly longer medially than next the eye. Pronotum shallowly, roundly concave behind. Elytra rather broad, second cross vein present.

External genitalia.—Last ventral segment of female twice as long as preceding segment, lateral margins produced and lateral angles rounded, posterior margin excavated across entire width half way to the base. Excavation roughly a broad V-shape, becoming suddenly wider half the way from the bottom. Male valve with lateral margins straight and converging, anterior and posterior margins parallel, anterior margin nearly twice as wide as posterior margin. Plates slender, outer margins parallel and curved upward, the plates thus appearing tubular. Outer margins of plates notched near tip. Tips of plates curved upward and folded together caudally, exceeding pygofer.

Internal male genitalia.—Posterior portion of style very broad apically, outer point slightly longer than inner. Inner margin of styles serrate distally, outer submargins bearing a few fine hairs. Ventral tooth of style very blunt. Aedeagus short, spines of the anal tube collar long.

Described from Arizona. There are specimens at hand from numerous localities in that State and from Texas, Florida, and Mexico. DeLong and Davidson (*12*) also recorded this species from Florida. Cotypes examined. Types in the collection of Iowa State College, Ames, Iowa.

ACERATAGALLIA BIGELOVIAE (Baker)

(Fig. 12, D, E, F; fig. 18, K, L; pl. 2, I)

Baker (*1, p. 26*) described this species as an *Agallia* in 1896. Robust, the female genital segment divided into four lobes and the male plates resembling those of *A. gillettei*. Length 2.5–2.75 mm.

Color.—Pale cinereous to brown with fuscous to black markings. Face pale, frontal sutures, median line on clypeus, broken transverse bars on frons, and arcs between frons and vertex, fuscous to brown. Vertex next the eyes and each side of median line faintly brown; spots above ocelli black. Pronotum with depressed anterior submargin and six longitudinal stripes irregularly, and often indistinctly, fuscous. Basal triangles of scutellum black or sometimes obsolete. Elytra brownish or sometimes with a whitish bloom; veins, except on clavus and base of corium, fuscous. Clavus often with black marks. Inner margins of male plates black.

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Structure.—Small and robust. Vertex strongly produced and somewhat tumid, a very little longer medially than next the eyes. Pronotum usually very short, hind margin nearly straight. Elytra broad, sometimes barely exceeding abdomen in length, usually longer; second cross vein between sectors usually present.

External genitalia.—Last ventral segment of female rather short, lateral margins straight, hind margin consisting of a pair of bluntly pointed lateral lobes and a smaller pair of lobes each side of the middle, the segment thus incised three times. Male valve short and transverse, shorter than in *A. gillettei*, lateral margins oblique, posterior margin concave. Plates long, slender, and curving, lateral margins turned up, tips appressed, narrower than in *A. gillettei* and turned upward less abruptly.

Internal male genitalia.—Posterior portion of style distinctly foot shaped, outer point much produced, inner point obsolete, inner margin serrate apically. Ventral tooth situated near apex. Aedeagus short, dorsal and ventral portions at right angles in lateral view.

The small size and the internal and external genital characters of the male will separate this species from other closely related forms. *A. bigeloviae* is much less common than the larger *A. dondia* n. sp.

Baker described *bigeloviae* from a single female from New Mexico. Specimens are at hand from Colorado, Texas, Arizona, Kansas, Utah, and Idaho. Type in the United States National Museum collection (catalog no. 44014).

ACERATAGALLIA LOBATA n. sp.

(Fig. 12, M, N, O; fig. 18, U, V)

Most closely allied to *A. bigeloviae* but longer and less robust. Length 2.75–3.25 mm.

Color.—Much darker than *bigeloviae*, almost identical in general markings with *gillettei*.

Structure.—In structure, aside from genital characters, as well as color, this species is almost identical with *gillettei*, but the vertex is a little more produced:

External genitalia.—Last ventral segment of female as in *bigeloviae*. Male plates also similar to those of *bigeloviae* but proportionately larger.

Internal male genitalia.—Posterior portion of style with inner and outer points about equal, apex not at all footlike, posterior margin obliquely subtruncate, slightly sinuate. Ventral tooth a little larger and situated more basad than in *bigeloviae*.

The differences in size and the form of the male styles are characters sufficient to distinguish this species from *bigeloviae*, the only one with which it is likely to be confused.

Holotype male from Glendale, Nev., May 5, 1929, D. E. Fox. Allotype female from Las Vegas, Nev., June 8, 1929, D. E. Fox. Paratypes, numerous specimens of both sexes from St. George, Utah; Mesquite and Glendale, Nev.; Sacaton, Yavapai County, and Santa Cruz County, Ariz.; and Alpine, Winters, San Diego County, and San Jacinto Mountains, Calif. The specimens of this species that were first received for identification were placed as *A. bigeloviae*, but subsequent studies established its distinctiveness. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44650); paratypes in the collections of the University of of Kansas, E. D. Ball, and E. W. Davis.

ACERATAGALLIA APLOPAPPI n. sp.

(Fig. 12, P, Q, R; fig. 18, O, P; pl. 2, H)

Very robust, the female genital segment similar to that of *A. bigeloviae* but with lobes pointed; the male plates strongly curved, tips blunt and diverging. Length 2.75–3 mm.

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Color.—General ground color pale yellowish. Front very faintly tinged with pink. Eyes dark, spots on vertex above ocelli black. Vertex and pronotum faintly longitudinally marked with brown. Scutellum sometimes with fuscous triangular spots basally. Elytra whitish, veins brown. Median pair of lobes of female genital segment brown, tips and posterior one half of inner margins of male plates smoky black.

Structure.—Short and broad, vertex strongly produced, rather tumid, very slightly longer medially than laterally. Head much wider than pronotum. Pronotum very short, anterior margin broadly rounded, posterior margin straight. Elytra short and broad, barely exceeding tip of abdomen in length in both sexes: Second cross vein between sectors present.

External genitalia.—Last ventral segment of female short, lateral margins straight, posterior margin angularly notched half way to the base medially and nearly to the base on each side, leaving two lateral and two median lobes, all bluntly pointed and closely appressed to the pygofer, the median pair appearing inlaid. Male valve rather narrow, about three times as wide as median length, lateral margins straight, obliquely converging, posterior margin concave. Plates arched downward, united and broad basally, narrowing gradually to near tips, then becoming slightly wider, tips diverging and bluntly rounded, exceeding pygofer in length. Pygofer covered laterally with fine whitish hairs.

Internal male genitalia.—Posterior portion of style somewhat foot shaped, outer point bluntly rounded, inner point scarcely produced, inner margin minutely serrate, outer margin and under side set with very fine straight hairs. Style without ventral tooth. Distal portion of aedeagus bent at right angles, short.

Superficially this species resembles *A. bigeloviae*, but is larger and easily distinguished by the genital characters of both sexes. All the specimens of the large series at hand are very light, but darker forms may be expected.

Holotype male and allotype female from Pima County, Ariz., July 27, 1927, R. H. Beamer. Paratypes, many specimens of both sexes from the same locality and from Mescal, Maricopa County, Phoenix, Tempe, Benson, Coconino County, and Tucson, Ariz.; and Belen, N. Mex. E. D. Ball reports that this species is taken commonly on *Aplopappus*, and this is no doubt the normal host. Holotype, allotype, and paratypes in the collection of the University of Kansas; paratypes in the United States National Museum collection (catalog no. 44015) and in the collections of E. D. Ball and Kansas State College.

ACERATAGALLIA DONDIA n. sp.

(Fig. 12, J, K, L; fig. 18, W, X; pl. 2, G)

Robust, but much larger than *A. bigeloviae*, and with the apices of the male styles much more convex. Length of male 3.25–3.5 mm, of female 3.5–3.75 mm.

Color.—Light yellowish brown, marked with brown and fuscous, about as in *A. bigeloviae*. Very pale specimens may have only the black spots on vertex and scutellum.

Structure.—General proportions about as in *bigeloviae*, vertex a little less produced but distinctly longer medially than next the eye. Pronotum short, posterior margin shallowly concave. Elytra long, extending well beyond abdomen, second cross vein between sectors present.

External genitalia.—Last ventral segment of female as in *bigeloviae*, with the hind margin 4-lobed. Male valve rather short and transverse, posterior margin truncate, lateral margins oblique. Plates slender, closely appressed, tapering to slender tips, lateral margins curved upward and tips bent broadly upward behind. Plates more tapering than in *bigeloviae* and more slender than in the following species.

Internal male genitalia.—Posterior portion of style long, tip club shaped, outer point well produced and sharp, inner points more produced than in *A. bigeloviae*, inner margin serrate on apical one half, very coarsely so distally, apex broadly, convexly rounded, ventral tooth of style situated near apex, large and slightly hooked. Aedeagus proportionately small, abruptly bent at right angles medially.

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This form is very closely related to *A. bigeloviae*, but because of the genital characters and the great difference in size it can hardly be considered the same. Most references in literature to *bigeloviae* probably apply to this species, the commonest species of the *bigeloviae* group.

Holotype male and allotype female from Thermal, Calif., February 14, 1913, from *Dondia* sp., H. O. Marsh. Paratypes, numerous specimens of both sexes from the same locality and from Ontario, Calif.; Overton, Glendale, and Las Vegas, Nev.; Tucson and Sacaton, Ariz. Specimens also at hand from Colorado. Most of the specimens at hand are from *Dondia*, evidently the normal host. Holotype, allotype, and paratypes in the United States National Museum collection (catalog no. 44016); paratypes in the collections of the University of Kansas, E. D. Ball, E. W. Davis, and Colorado State College.

ACERATAGALLIA VASTITATIS n.sp.

(Fig. 12, S; fig. 18, Q, R)

Superficially identical with *A. dondia*, but with the male plates broader and scarcely or not at all narrowed apically. Length 3.5–3.75 mm.

Color.—About as in very pale examples of *dondia*, but darker specimens may be expected. In the specimens at hand the inner margins of the male plates are not black.

Structure.—Slightly less robust and with the vertex less produced than in *dondia*. Elytra extending well beyond apex of abdomen, the tips, especially of the males, flaring. Second cross vein between sectors present.

External genitalia.—Female genital segment apparently identical with that of *A. dondia*, but male valve longer than in that species and male plates broader, less tapering, and with the lateral margins not so much reflexed upward.

Internal male genitalia.—Posterior portion of style intermediate in character between *dondia* and *aplopappi*, apex foot shaped, outer point broad and bluntly rounded, inner point scarcely produced, inner margin very finely serrate near apex, outer submargin below bearing a few very fine hairs. Ventral tooth of style situated near apex as in *dondia* but much smaller than in that species.

This form is much less common than the preceding one. It probably occurs on *Pluchea sericea*. Holotype male and allotype female from Lund, Utah, July 13, 1928, E. W. Davis. Paratypes, numerous specimens of both sexes from St. George and Lund, Utah; Overton and Glendale, Nev.; and Littlefield, Ariz. Types in the United States National Museum collection (catalog no. 44017) and the collection of E. W. Davis.

ACERATAGALLIA TERGATA (Van Duzee)

(Fig. 13, A, B, C; fig. 18, Y, Z)

Described as an *Agallia* by Van Duzee (*44, p. 172*) in 1923. Robust, allied to *A. dondia*, but smaller and without the black spots on the vertex. Length 3–3.25 mm.

Color.—General ground color pale dirty cinereous, covered with a whitish bloom. Head and anterior margin of pronotum tinged with yellowish orange, eyes dark. Elytra whitish, venation obscure. Median portion of female genital segment and inner margins of male plates brown.

Structure.—Quite robust, vertex well produced and distinctly longer medially than next the eyes. Pronotum short, posterior margin broadly and shallowly excavated. Elytra short and broad, second cross vein between sectors present.

External genitalia.—Last ventral segment of female with posterior margin incised three times nearly to the base, making four lobes, the outer ones larger and blunt, the inner pair short and pointed. Male valve transverse, rather short, posterior margin slightly concave, lateral margins oblique. Plates broad,

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lateral margins curved upward and narrowing slightly to upturned tips which exceed pygofer in length. Plates inclosed by pygofer laterally at base.

Internal male genitalia.—Posterior portion of style slender and sinuately curved, outer point broad, but narrowing and with apex sharp, inner point scarcely produced, entire tip boot shaped, inner margin serrate posteriorly, outer submargin bearing slender hairs above. Ventral tooth of style prominent. Style much as in *A. vastitatis* but with shank more curved, outer point sharper, and ventral tooth situated farther from the apex.

Although closely related to the other species of the *bigeloviae* group, this form should be easily identified by the whitish bloom and the absence of the black spots on the vertex. Described from Tortuga Island and San Marcos Island, Gulf of California. Mr. Van Duzee collected his type series on *Encelia*, which is probably the normal host. There are also specimens at hand from Arizona. Paratypes examined through the kindness of Mr. Van Duzee. Types in collection of California Academy of Science; paratypes in United States National Museum collection (catalog no. 44018).

The genus AGALLIANA new genus

Form and general aspect of *Aceratagallia*, but with the surface of the pronotum coarsely punctate instead of transversely striated and with the styles of the male genitalia forked posteriorly.

Vertex short and of almost uniform length, with a pair of dark spots on the posterior margin above the ocelli. Pronotum with anterior margin broadly and evenly curved, lateral margins short, posterior margin nearly straight, the entire surface, except the lateral margins and the anterior margin laterally, marked with small round, or sometimes transversely elongate pits, which are usually black. Elytra longer than abdomen, without appendices; venation distinct, each elytron with four apical and three anteapical cells. Ovipositor of female exceeding pygofer in length. Internal male genitalia with the styles forked posteriorly, spine of tenth segment large, either forked or single.

Type of the genus, *Bythoscopus sticticollis* Stål.

At present only the above-named species is included in this genus, but several apparently unnamed forms from South America also belong here.

AGALLIANA STICTICOLLIS (Stål)

(Fig. 13, D, E, F; fig. 18, S, T; pl. 3, L)

Stål (*34, p. 291*) described this species in 1859 as a *Bythoscopus*. It was described again in 1895 by Uhler (*37, p. 81*) as *Agallia ustulata* and again in 1923 by DeLong and Wolcott (Wolcott, *45, p. 258*) as *Agallia carrotovora*. Resembling *Aceratagallia sanguinolenta* in form but pronotum with many tiny, circular pits. Length 3.25–3.5 mm.

Color.—Yellowish brown to brown, marked with fuscous. Frontal sutures, antennal pits, tips of transverse arcs on frons, arms of inverted Y, and narrow, double median line on vertex and sides of vertex next eyes varying from brown to fuscous. Spots on posterior margin of vertex above ocelli black. Entire surface of pronotum with black points except anterior margin laterally, these areas margined behind by brown or fuscous. Scutellum with basal angles and sometimes median stripe dark. Elytra brown to subhyaline with veins black or correspondingly darker, except first sector of clavus, tip of second sector of clavus, claval suture basally and apically, and a portion of base of radius. Edges of notch in posterior margin of female genital segment brown.

Structure.—Vertex subangularly rounded, slightly longer medially than next the eyes. Pronotum except anterior margin laterally covered with shallow,

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pitlike depressions. Hind margin of pronotum slightly angularly concave. Elytra long, second cross vein present.

External genitalia.—Last ventral segment of female nearly twice as long as preceding segment, lateral angles produced and subangularly rounded, hind margin shallowly concave with a median v-shaped notch. Male valve rather short and transverse. Plates nearly parallel sided, slightly broadened basally and gradually rounded distally, slightly exceeding pygofer in length.

Internal male genitalia.—Aedeagus in lateral view stout and short, near the tip bearing a pair of lateral spines that curve sharply downward. The position of these spines varies from near the tip to almost the middle of the distal portion of the aedeagus. Dorsal spine of tenth segment appearing as a long, straight spine in lateral view but in caudal aspect forked, with the inner fork the shorter of the two. Styles ending caudally in two parts, the inner foot shaped, the outer blunt.

Described from Rio de Janeiro. There are specimens at hand from the States of Rio de Janeiro, Minas Geraes, Matto Grosso, Amazonas, and Pernambuco, Brazil; and from British Guiana, Trinidad, Tobago, St. Vincent, Dominican Republic, Puerto Rico, and Cuba. The specimens of this long series agree in every respect except that the position of the lateral spines on the aedeagus seems to be variable and the character evidently has no specific significance. In general the spines are nearer the tip of the aedeagus in specimens from the Greater Antilles and nearer the middle of the distal portion in examples from Rio de Janeiro, while those from intervening localities are intermediate in position. Osborn (*24, p. 12*) has identified a specimen from Bolivia as *A. sticticollis* (Stål), but specimens at hand from Bolivia and Argentina, while superficially very like those from Rio de Janeiro, differ markedly in internal male genitalia and slightly in size, coloring, and external male genitalia. Since Stål's specimens were from Brazil, it is probable that the Bolivian and Argentine specimens represent an unnamed form, while Stål's name should be applied to the species here described and figured. Type probably lost. O. Lundblad states that the type is not in the Stockholm Museum at Stockholm, Sweden.

LITERATURE CITED

(1) Baker, C. F.
1896. NEW HOMOPTERA RECEIVED FROM THE NEW MEXICO AGRICULTURAL EXPERIMENT STATION 2. Psyche 7, sup. 12:24–26.

(2) ———
1898. SOME NEW BYTHOSCOPINAE WITH NOTES ON OTHERS. Psyche 8:197–201.

(3) ———
1901. NOTES ON MACROPSIS AND AGALLIA (JASSIDAE). Psyche 9:151–153.

(4) Ball, E. D.
1900. NOTES ON THE SPECIES OF MACROPSIS AND AGALLIA OF NORTH AMERICA. Psyche 9:126–130.

(5) ———
1909. SOME INSECTS INJURIOUS TO TRUCK CROPS. IV. THE LEAFHOPPERS OF THE SUGAR BEET AND THEIR RELATION TO THE "CURLY-LEAF" CONDITION. U.S. Dept. Agr., Bur. Ent. Bul. 66 (pt. 4):33–52, illus.

(6) Berg, C.
1879. HEMIPTERA ARGENTINA, ENUMERAVIT SPECIESQUE NOVAS DESCRIPSIT. 316 p. [Reprinted from An. Soc. Cient. Argentina, v. 7–8, 1878–79.]

(7) ———
1881. SINONIMIA Y DESCRIPCION DE ALGUNOS HEMIPTEROS DE CHILE, DEL BRASIL Y DE BOLIVIA. An. Soc. Cient. Argentina 12: [259]–272.

(8) ———
1884. ADDENDA ET EMENDANDA AD HEMIPTERA ARGENTINA. 213 p. [Reprinted from An. Soc. Cient. Argentina, v. 16–17, 1883–84.]

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(9) ———
1895. HEMIPTEROS DE LA TIERRA DEL FUEGO. COLECIONADOS POR EL SEÑOR CARLOS BACKHAUSEN. An. Mus. Nac. Hist. Nat. Buenos Aires 4 : [195]–206.

(10) CARTER, W.
1930. ECOLOGICAL STUDIES OF THE BEET LEAF HOPPER. U.S. Dept. Agr. Tech. Bul. 206, 115 p., illus.

(11) CURTIS, J.
1833. CHARACTERS OF SOME UNDESCRIBED GENERA AND SPECIES, INDICATED IN THE "GUIDE TO AN ARRANGEMENT OF BRITISH INSECTS." Ent. Mag. 1:186–199.

(12) DELONG, D. M., AND DAVIDSON, R. H.
1931. THE GENUS AGALLIA—EXTERNAL CHARACTERS USED TO DISTINGUISH THE SPECIES INJURING ECONOMIC CROPS. Ohio Jour. Sci. 31: 377–385, illus.

(13) FAWCETT, G. L.
1925. ENCRESPAMIENTO DE LAS HOJAS DE LA REMOLACHA AZUCARERA. Rev. Indus. y Agri. de Tucumán 16 : [39]–46, illus.

(14) ———
1927. THE CURLY TOP OF SUGAR BEET IN THE ARGENTINE. Phytopathology 17 : 407–408.

(15) FORBES, S. A.
1885. 14TH REPORT OF THE STATE ENTOMOLOGIST ON THE NOXIOUS AND BENEFICIAL INSECTS OF THE STATE OF ILLINOIS [REPORT FOR 1884]. 136 p., illus.

(16) GIBSON, E. H.
1916. THE CLOVER LEAFHOPPER AND ITS CONTROL IN THE CENTRAL STATES. U.S. Dept. Agr. Farmers' Bul. 737, 8 p., illus.

(17) HENDERSON, C. F.
1928. EXPLORATION IN THE ARGENTINE REPUBLIC FOR PARASITES OF THE BEET LEAFHOPPER, EUTETTIX TENELLUS (BAKER). Jour. Econ. Ent. 21: 863–871, illus.

(18) KIRKALDY, G. W.
1907. LEAFHOPPERS-SUPPLEMENT (HEMIPTERA). Hawaii. Sugar Planters' Assoc. Expt. Sta., Div. Ent. Bul. 3, 186 p., illus.

(19) LATHROP, F. H.
1917. A PRELIMINARY LIST OF THE CICADELLIDAE (HOMOPTERA) OF SOUTH CAROLINA, WITH DESCRIPTIONS OF NEW SPECIES. Ohio Jour. Sci. 17:119–131, illus.

(20) ———
1919. THE CICADELLIDAE OR LEAF-HOPPERS OF SOUTH CAROLINA. S.C. Agr. Expt. Sta. Bul. 199, 119 p., illus.

(21) LAWSON, P. B.
1920. THE CICADELLIDAE OF KANSAS. Kans. Univ. Sci. Bul. (whole ser. 22, no. 1) 12, no. 1, 306 p., illus.

(22) OLSEN, C. E.
1922. A NEW SPECIES OF AGALLIA (A. LINGULATA N. SP.), WITH NOTES ON OTHER CICADELLIDAE. Bul. Brooklyn Ent. Soc. 17:127–131, illus.

(23) OSBORN, H.
1912. LEAFHOPPERS AFFECTING CEREALS, GRASSES, AND FORAGE CROPS. U.S. Dept. Agr., Bur. Ent. Bul. 108, 123 p., illus.

(24) ———
1923. NEOTROPICAL HOMOPTERA OF THE CARNEGIE MUSEUM. PART 1. REPORT UPON THE UNDESCRIBED SPECIES OF AGALLIA AND IDIOCERUS FROM TROPICAL AMERICA CONTAINED IN THE CARNEGIE MUSEUM, 1920. Ann. Carnegie Mus. 15 (1):8–26, illus.

(25) ———
1924. NEOTROPICAL HOMOPTERA OF THE CARNEGIE MUSEUM. PARTS 3 AND 4. REPORT UPON THE COLLECTIONS IN THE SUBFAMILY BYTHOSCOPINAE, WITH DESCRIPTION OF NEW SPECIES. Ann. Carnegie Mus. 15:383–462, illus.

(26) ———
1926. FAUNISTIC AND ECOLOGIC NOTES ON CUBAN HOMOPTERA. Ann. Ent. Soc. Amer. 19:335–366, illus.

(27) ———
1929. NOTES ON PORTO RICAN HOMOPTERA. Jour. Dept. Agr. Porto Rico 13:81–112, illus.

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(28) ——— AND BALL, E. D.
1899. STUDIES OF NORTH AMERICAN JASSOIDEA. Davenport Acad. Nat. Sci. Proc. (1897–99) 7:45–100, illus.

(29) POOS, F. W.
1929. LEAFHOPPER INJURY TO LEGUMES. Jour. Econ. Ent. 22:146–153, illus.

(30) PROVANCHER, L.
1872. DESCRIPTION DE PLUSIERS HÉMIPTÈRES NOUVEAUX. Nat. Canad. 4:73–79, 103–108, 319–320, 350–352, 376–379.

(31) SAY, T.
1830–31. DESCRIPTIONS OF NEW NORTH AMERICAN HEMIPTEROUS INSECTS, BELONGING TO THE FIRST FAMILY OF THE SECTION HOMOPTERA OF LATREILLE. Jour. Acad. Nat. Sci. Phila. 6:235–244, 299–314. (Reprinted in The Complete Writings of Thomas Say on the Entomology of North America, [etc.] 1859.)

(32) SCOTT, J.
1874. ON CERTAIN BRITISH HEMIPTERA-HOMOPTERA. Ent. Mo. Mag. 10:235–242.

(33) SEVERIN, H. H. P., AND HENDERSON, C. F.
1928. BEET LEAFHOPPER, EUTETTIX TENELLUS (BAKER), DOES NOT OCCUR IN THE ARGENTINE REPUBLIC. Jour. Econ. Ent. 21:542–544.

(34) STÅL, C.
1859. HEMIPTERA. K. Svenska Fregatten Eugenies resa omkring Jorden under befäl af C. A. Virgin åren 1851–1853, v. 2, Zoologi, pt. 4, Insekter, p. 219–298, illus.

(35) ———
1858–60. BIDRAG TILL RIO JANEIRO-TRAKTENS HEMIPTERA-FAUNA. K. Svenska Vetensk. Akad. Handl. (n. F.) 2, no. 7, 84 p., 1858; 3, no. 6, 75 p., 1860.

(36) UHLER, P. R.
1876. LIST OF HEMIPTERA OF THE REGION WEST OF THE MISSISSIPPI RIVER, INCLUDING THOSE COLLECTED DURING THE HAYDEN EXPLORATIONS OF 1873. U.S. Dept. Int., Geol. and Geogr. Survey Bul. 5 (n.s.): [269]–361, illus.

(37) ———
1895. AN ENUMERATION OF THE HEMIPTERA-HOMOPTERA OF THE ISLAND OF ST. VINCENT, W. I. Zool. Soc. London, Proc. 1895: 55–84.

(38) VAN DUZEE, E. P.
1890. NEW CALIFORNIA HOMOPTERA. Ent. Amer. 6:35–38.

(39) ———
1892. A SYNOPTICAL ARRANGEMENT OF THE GENERA OF THE NORTH AMERICAN JASSIDAE, WITH DESCRIPTIONS OF SOME NEW SPECIES. Amer. Ent. Soc. Trans. 19:295–307.

(40) ———
1894. NEW NORTH AMERICAN HOMOPTERA—NO. VII. Canad. Ent. 26:89–93.

(41) ———
1907. NOTES ON JAMAICAN HEMIPTERA. A REPORT ON A COLLECTION OF HEMIPTERA MADE ON THE ISLAND OF JAMAICA IN THE SPRING OF 1906. Bul. Buffalo Soc. Nat. Sci. 8, no. 5, 97 p.

(42) ———
1909. OBSERVATIONS ON SOME HEMIPTERA TAKEN IN FLORIDA IN THE SPRING OF 1908. Bul. Buffalo Soc. Nat. Sci. 9:[149]–230, illus.

(43) ———
1917. CATALOGUE OF THE HEMIPTERA OF AMERICA NORTH OF MEXICO, EXCEPTING THE APHIDIDAE, COCCIDAE, AND ALEURODIDAE. Calif. Univ. Pubs., Tech. Bul., v. 2, 902 p.

(44) ———
1923. EXPEDITION OF THE CALIFORNIA ACADEMY OF SCIENCE TO THE GULF OF CALIFORNIA IN 1921. THE HEMIPTERA (TRUE BUGS, ETC.). Calif. Acad. Sci. Proc. (4) 12:[123]–200.

(45) WOLCOTT, G. N.
1923. "INSECTAE PORTORICENSIS." A PRELIMINARY ANNOTATED CHECK-LIST OF THE INSECTS OF PORTO RICO, WITH DESCRIPTIONS OF SOME NEW SPECIES. Jour. Dept. Agr. Porto Rico 7:1–313, illus.

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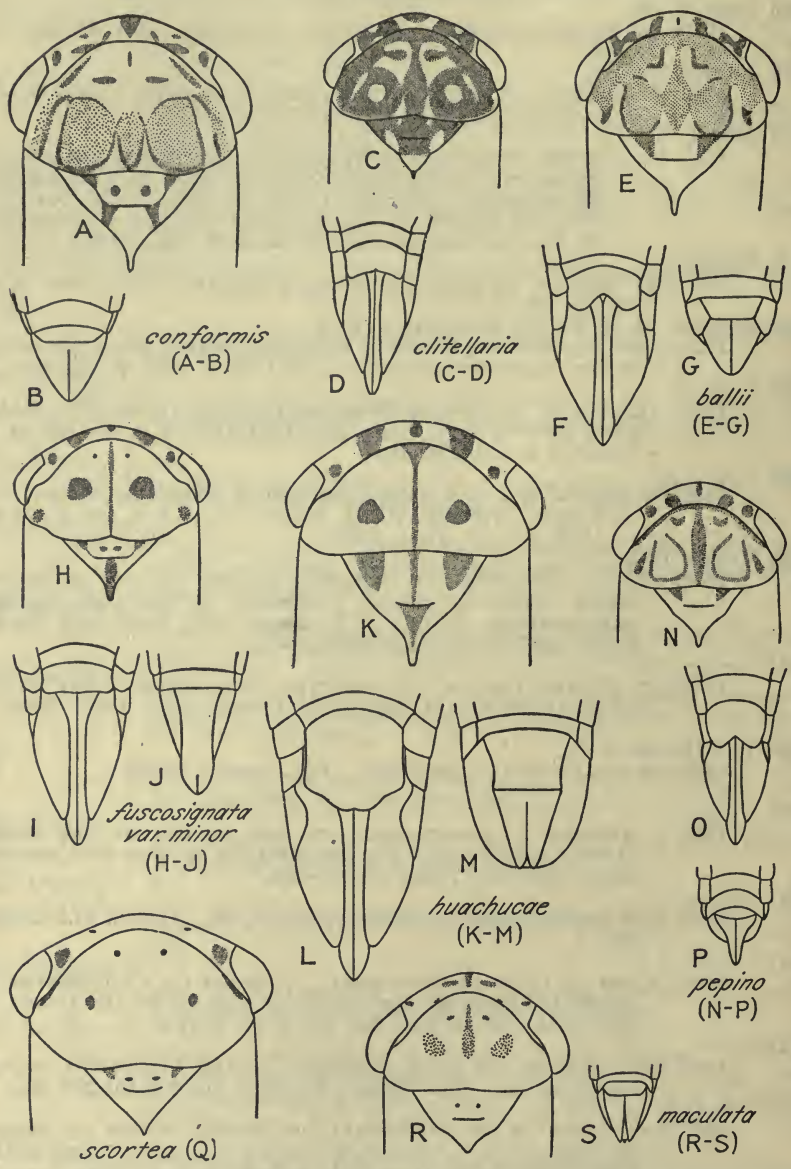

FIGURE 1.—External details of *Agalliopsis* spp.: A, Head and thorax, and B, male genitalia, of *A. conformis;* C, head and thorax, and D, female genitalia, of *A. clitellaria;* E, head and thorax, F, female genitalia, and G, male genitalia, of *A. ballii;* H, head and thorax, I, female genitalia, and J, male genitalia, of *A. fuscosignata* var. *minor;* K, head and thorax, L, female genitalia, and M, male genitalia, of *A. huachucae;* N, head and thorax, O, female genitalia, and P, male genitalia, of *A. pepino;* Q, head and thorax of *A. scortea;* R, head and thorax, and S, male genitalia, of *A. maculata.*

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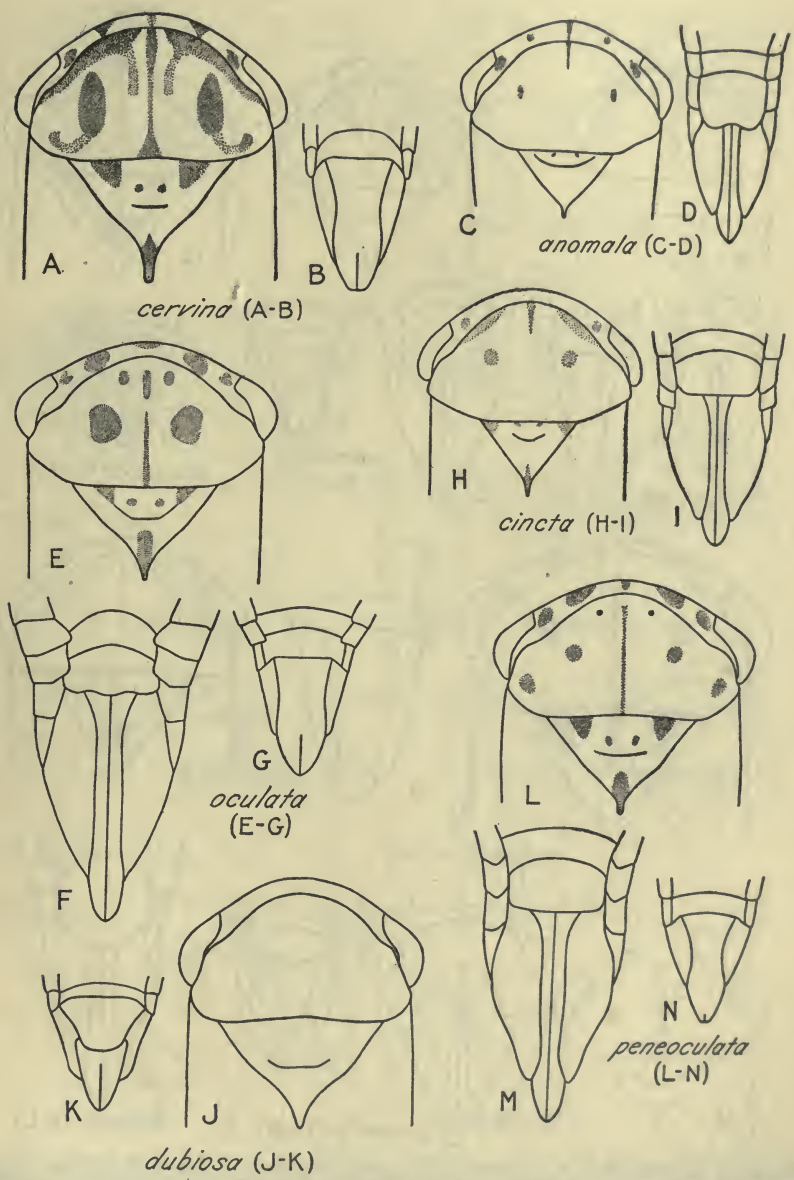

FIGURE 2.—External details of *Agalliopsis* spp.: A, Head and thorax, and B, male genitalia, of *A. cervina;* C, head and thorax, and D, female genitalia, of *A. anomala;* E, head and thorax, F, female genitalia, and G, male genitala, of *A. oculata;* H, head and thorax, and I, female genitalia, of *A. cincta;* J, head and thorax, and K, male genitalia, of *A. dubiosa;* L, head and thorax, M, female genitalia, and N, male genitalia, of *A. peneoculata.*

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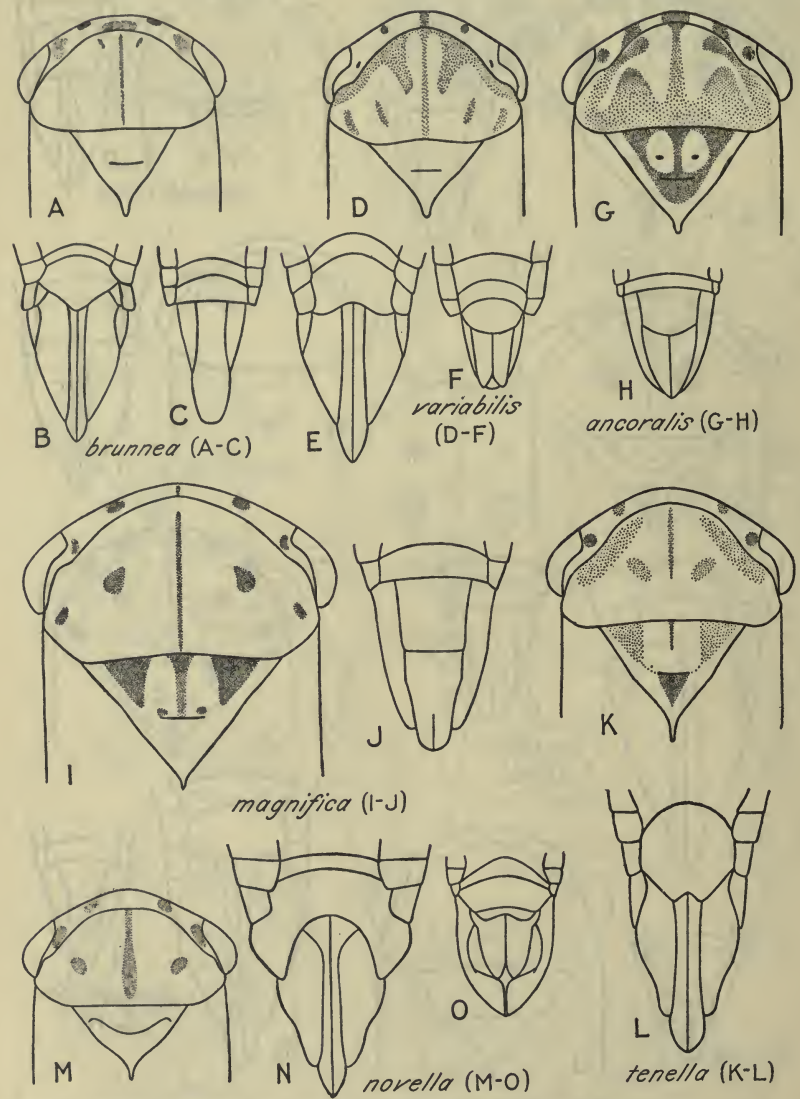

FIGURE 3.—External details of *Agalliopsis* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. brunnea;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. variabilis;* G, head and thorax, and H, male genitalia, of *A. ancoralis;* I, head and thorax, and J, male genitalia, of *A. magnifica;* K, head and thorax, and L, female genitalia, of *A. tenella;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. novella.*

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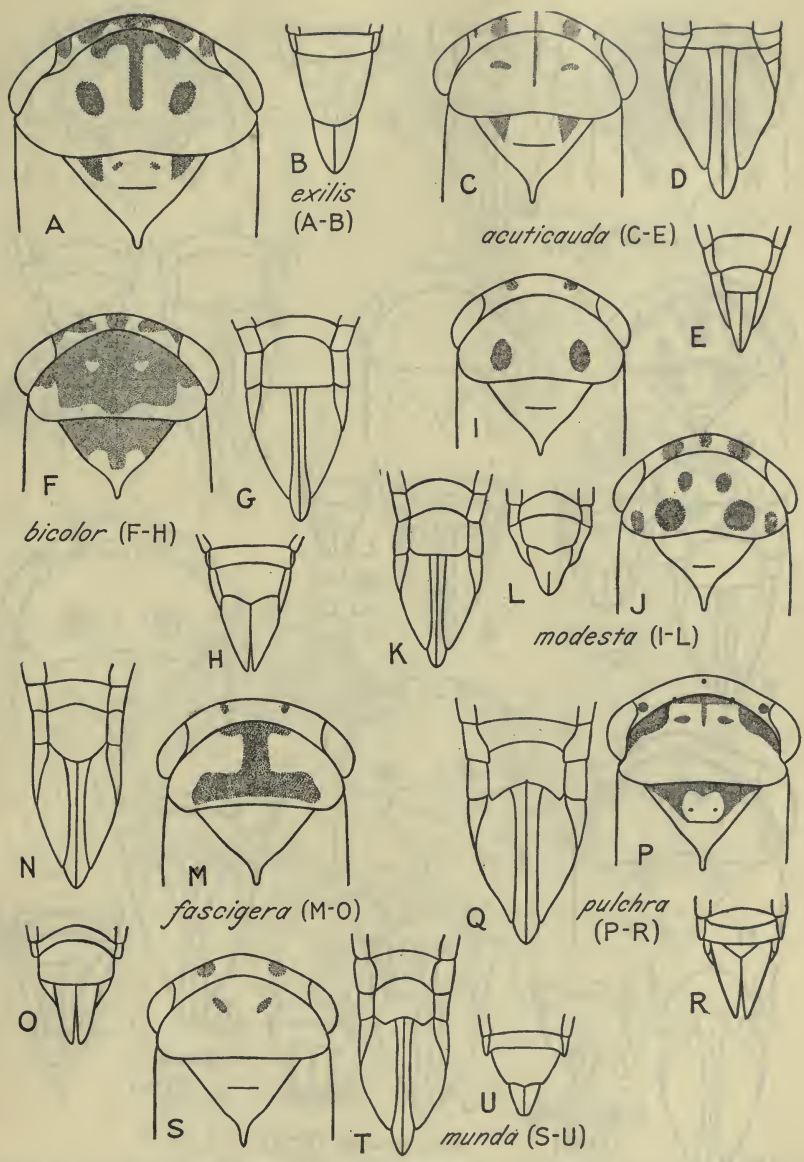

FIGURE 4.—External details of *Agalliopsis exilis* and *Agallia* spp.: A, Head and thorax, and B, male genitalia, of *A. exilis;* C, head and thorax, D, female genitalia, and E, male genitalia, of *Agallia acuticauda;* F, head and thorax, G, female genitalia, and H, male genitalia, of *A. bicolor;* I, head and thorax, J, same showing variation in color pattern, K, female genitalia, and L, male genitalia, of *A. modesta;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. fascigera;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. pulchra;* S, head and thorax, T, female genitalia, and U, male genitalia, of *A. munda.*

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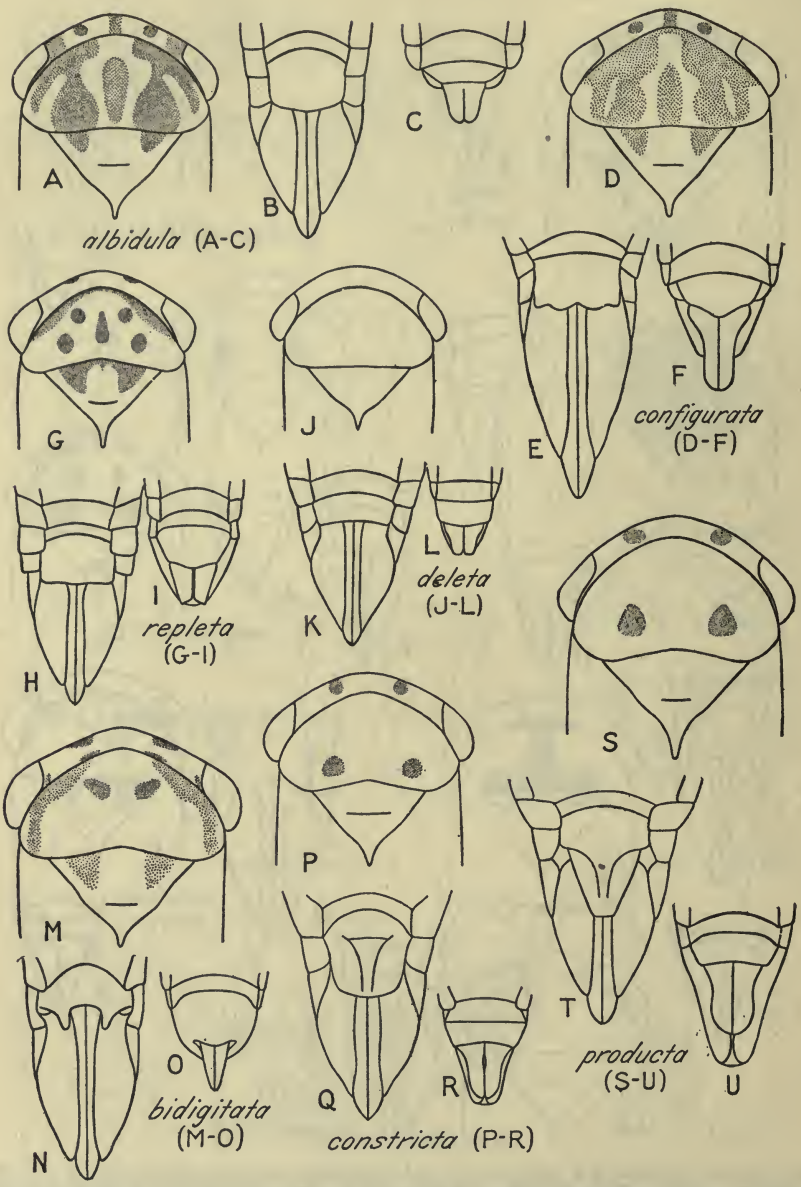

FIGURE 5.—External details of *Agallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. albidula;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. configurata;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. repleta;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. deleta;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. bidigitata;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. constricta;* S, head and thorax, T, female genitalia, and U, male genitalia, of *A. producta.*

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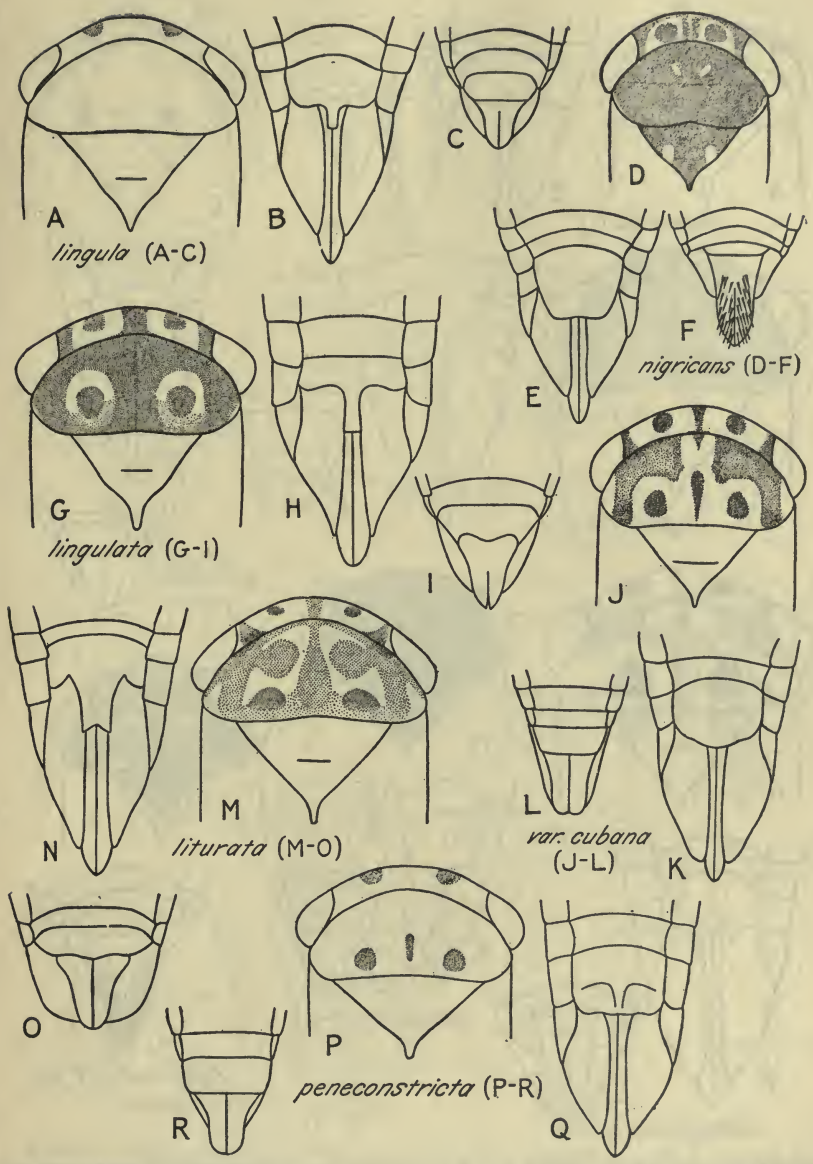

FIGURE 6.—External details of *Agallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. lingula;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. nigricans;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. lingulata;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. constricta* var. *cubana;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. liturata;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. peneconstricta*

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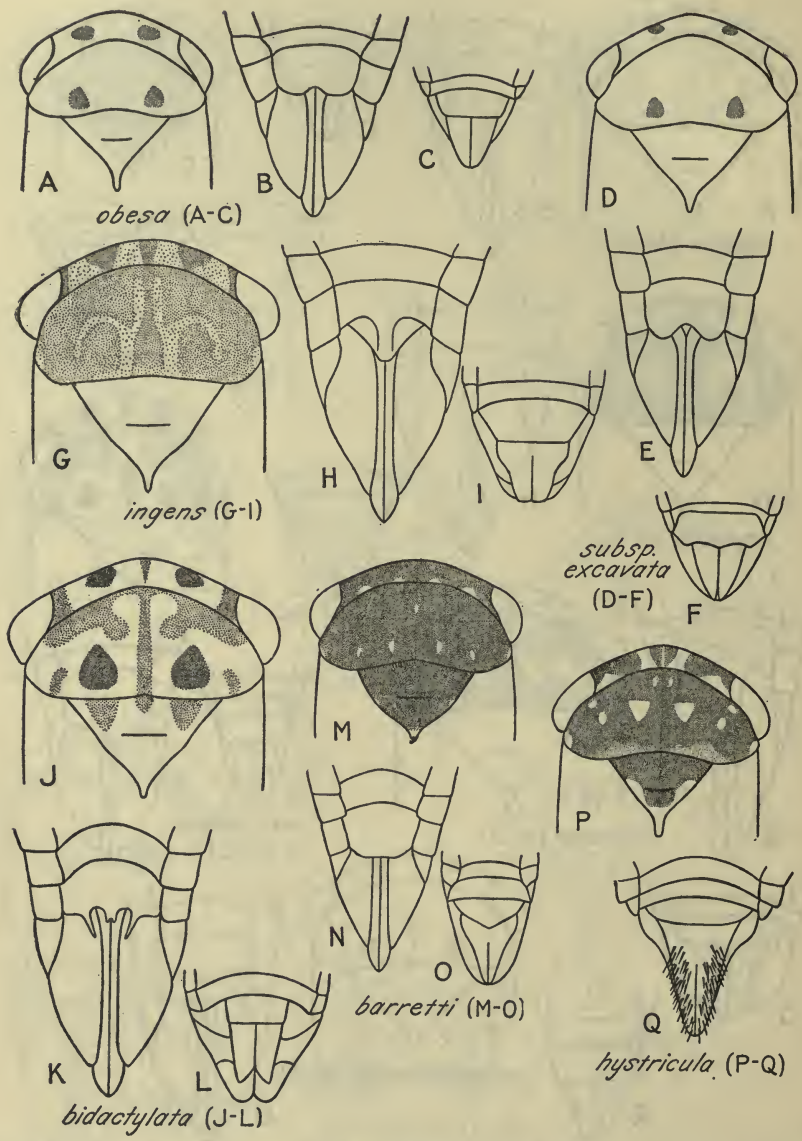

FIGURE 7.—External details of *Agallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. obesa;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. quadripunctata* subsp. *excavata;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. ingens;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. bidactylata;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. barretti;* P, head and thorax, and Q, male genitalia, of *A. hystricula.*

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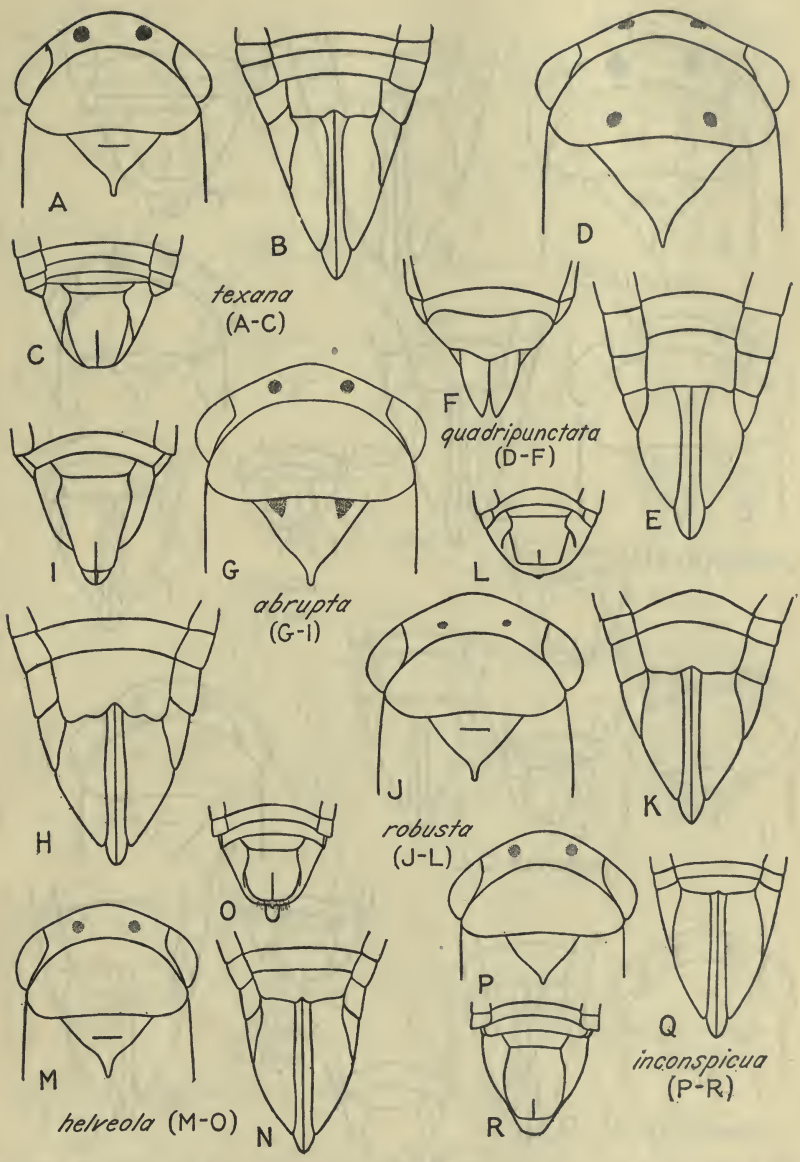

FIGURE 8.—External details of *Aceratagallia* spp. and *Agallia quadripunctata;* A, Head and thorax, B, female genitalia, and C, male genitalia, of *Aceratagallia texana;* D, head and thorax, E, female genitalia, and F, male genitalia, of *Agallia quadripunctata;* G, head and thorax, H, female genitalia, and I, male genitalia, of *Aceratagallia abrupta;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. robusta;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. helveola;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. inconspicua.*

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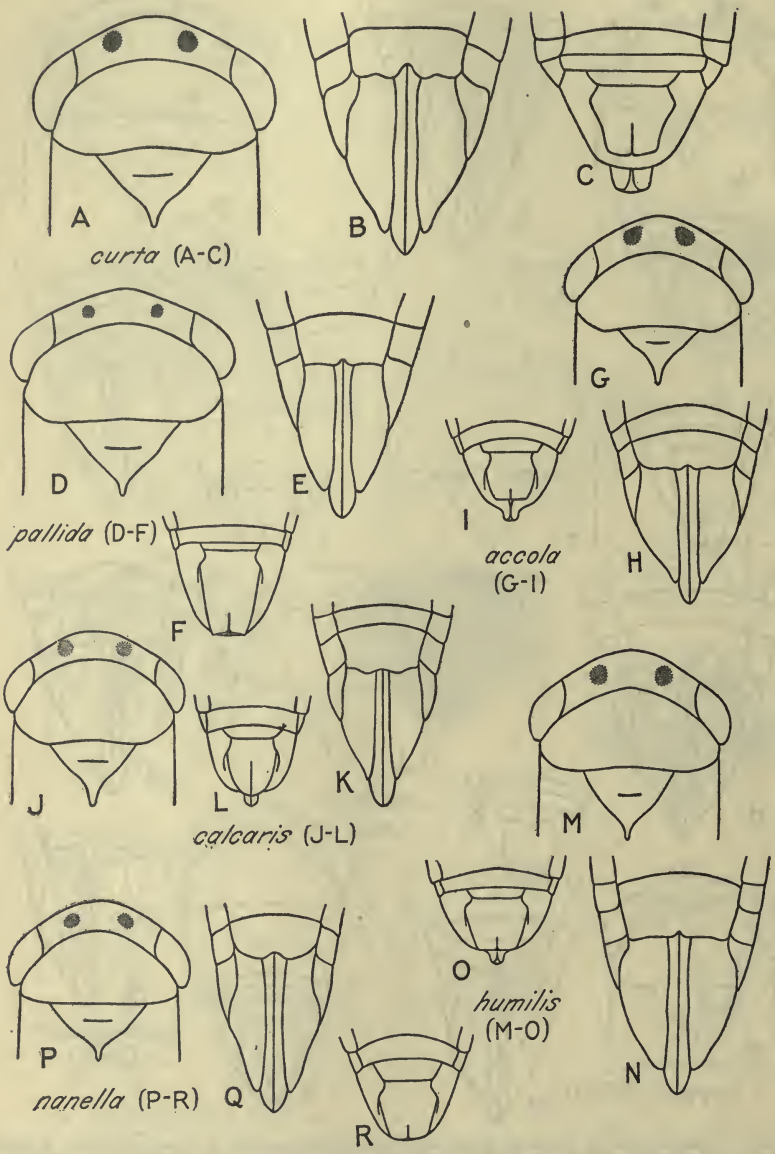

FIGURE 9.—External details of *Aceratagallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. curta;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. pallida;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. accola;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. calcaris;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. humilis;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. nanella.*

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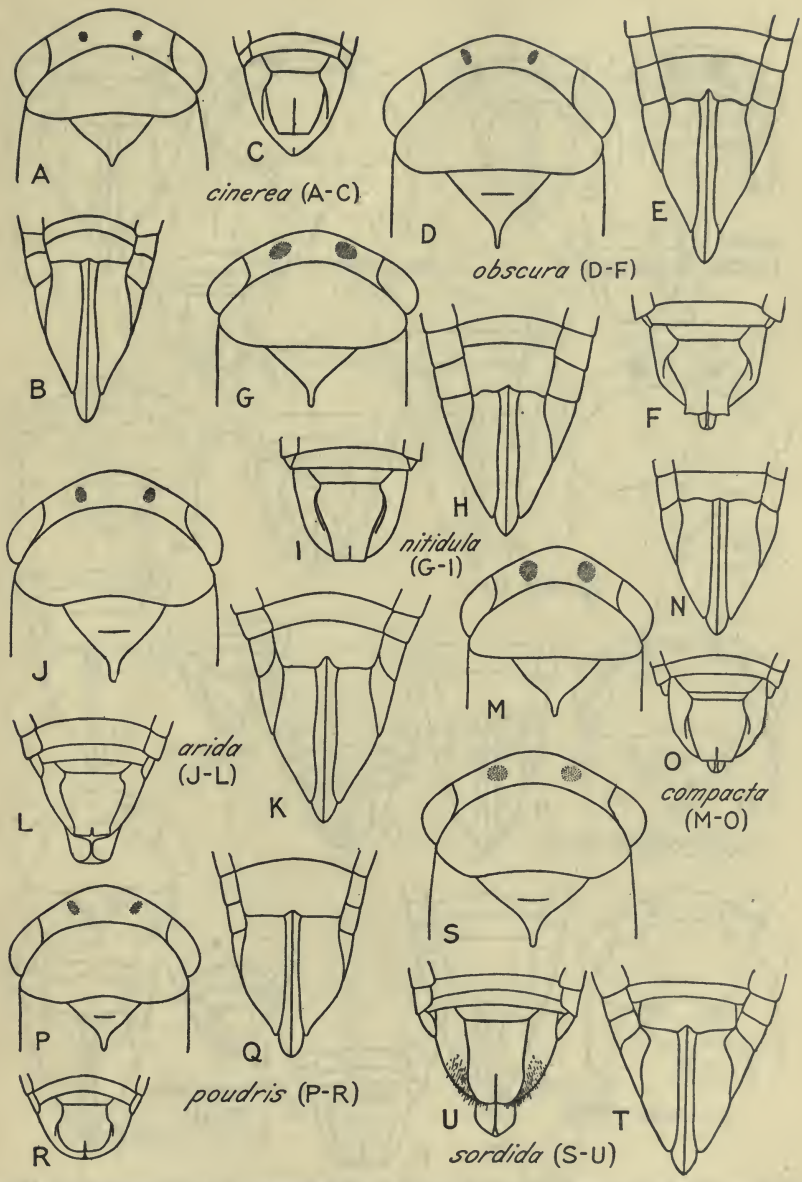

FIGURE 10.—External details of *Aceratagallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. cinerea;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. obscura;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. nitidula;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. arida;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. compacta;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. poudris;* S, head and thorax, T, female genitalia, and U, male genitalia, of *A. sordida.*

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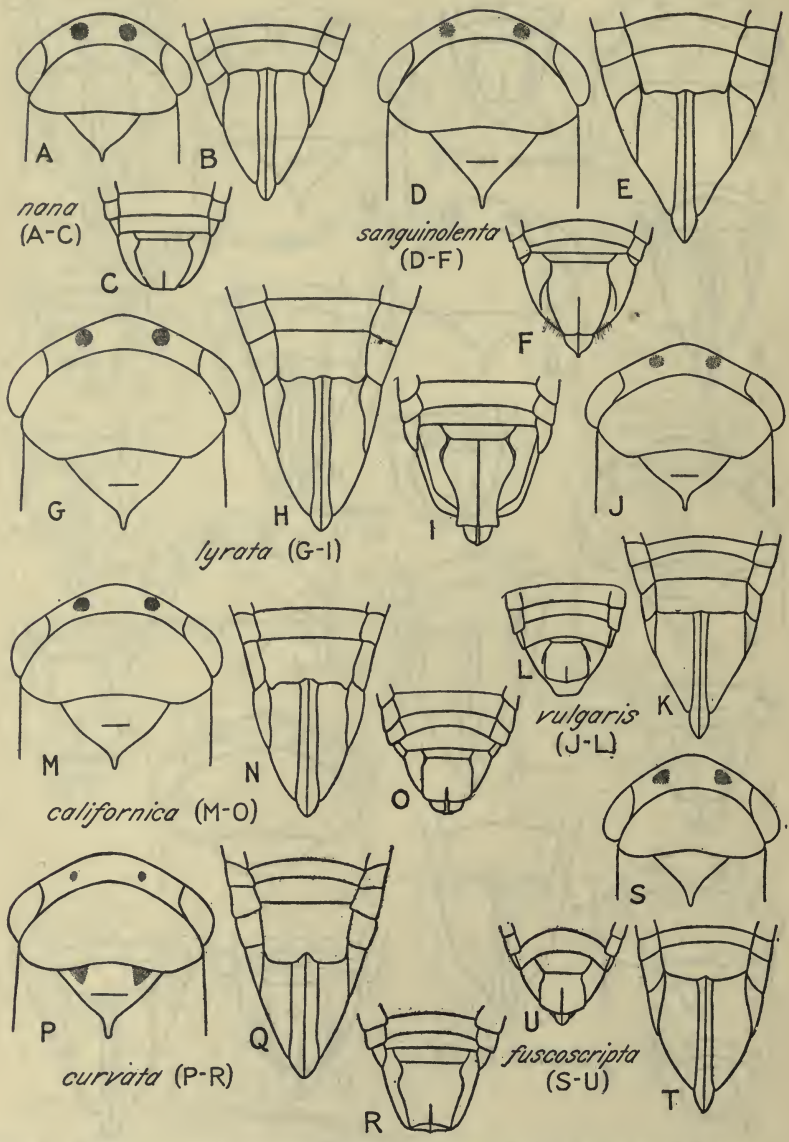

FIGURE 11.—External details of *Aceratagallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. nana;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. sanguinolenta;* G, head and thorax, H, female genitalia, and I male genitalia, of *A. lyrata;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. vulgaris;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. californica;* P, head and thorax, Q, female genitalia, and R, male genitalia, of *A. curvata;* S, head and thorax, T, female genitalia, and U, male genitalia, of *A. fuscoscripta.*

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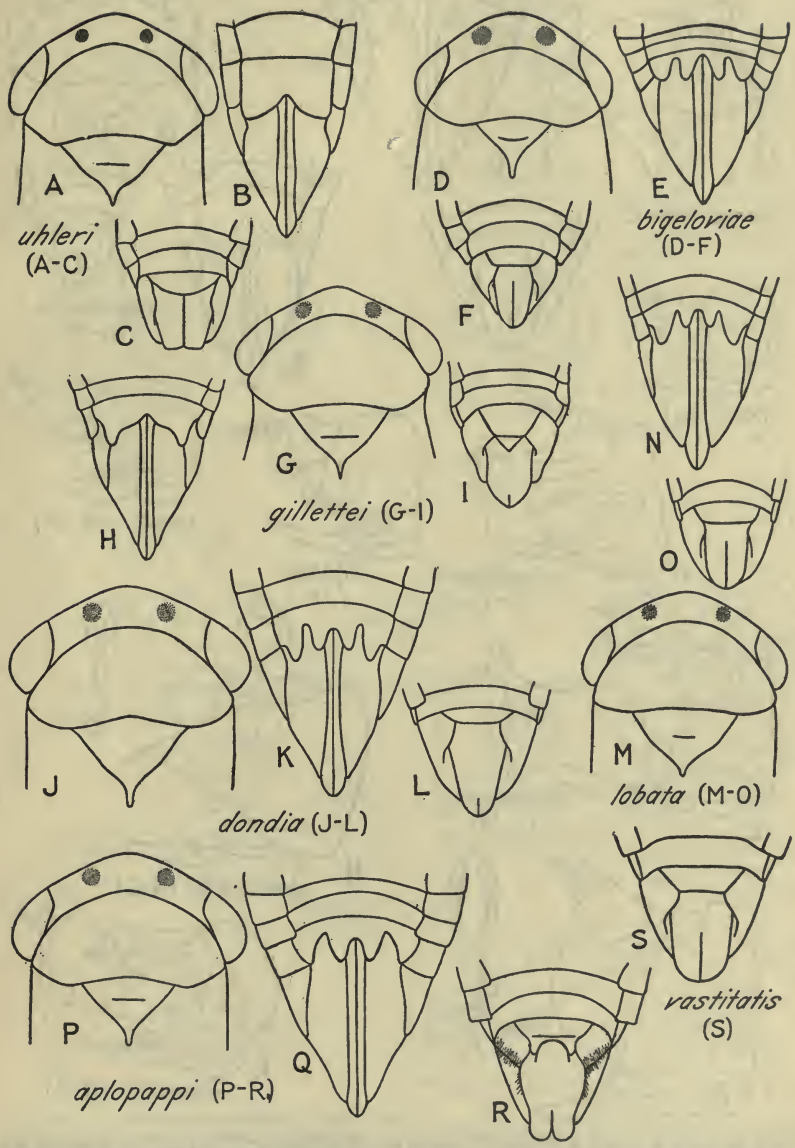

FIGURE 12.—External details of *Aceratagallia* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. uhleri;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. bigeloviae;* G, head and thorax, H, female genitalia, and I, male genitalia, of *A. gillettei;* J, head and thorax, K, female genitalia, and L, male genitalia, of *A. dondia;* M, head and thorax, N, female genitalia, and O, male genitalia, of *A. lobata;* P, head and thorax, Q, female genitalia, and R male genitalia, of *A. aplopappi;* S, male genitalia of *A. vastitatis.*

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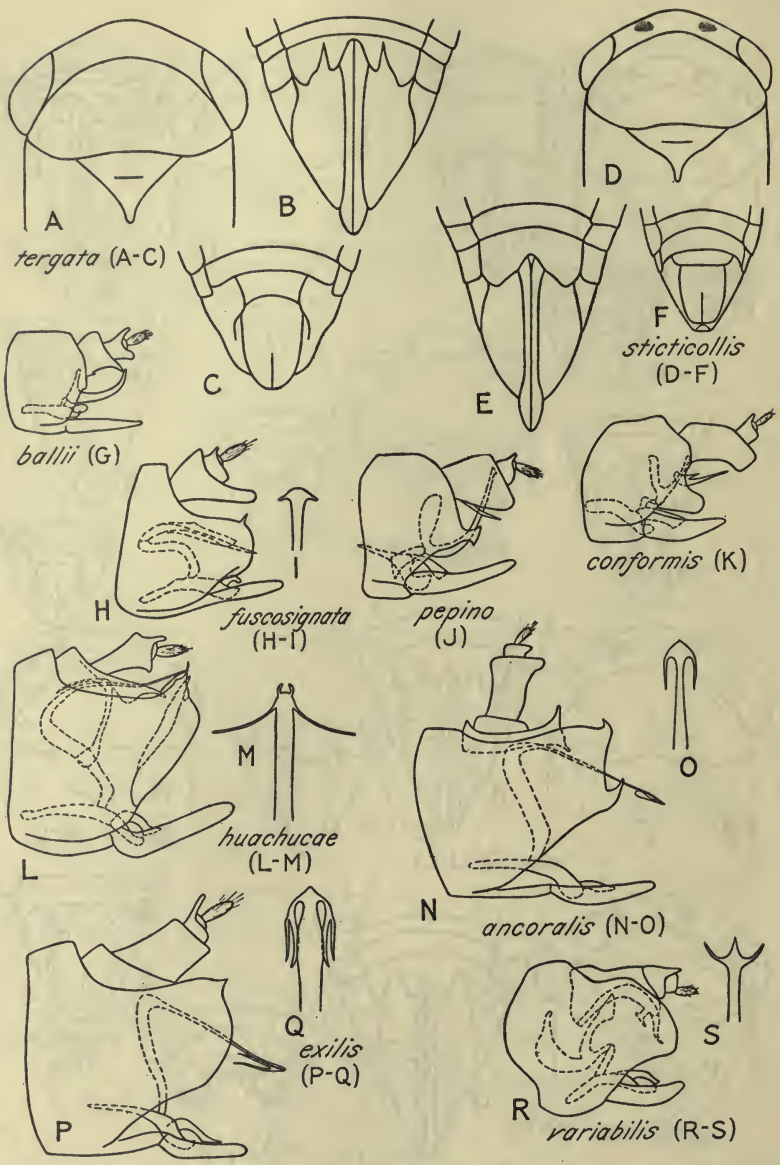

FIGURE 13.—External details of *Aceratagallia tergata* and *Agalliana sticticollis* and internal male genitalia of *Agalliopsis* spp.: A, Head and thorax, B, female genitalia, and C, male genitalia, of *A. tergata;* D, head and thorax, E, female genitalia, and F, male genitalia, of *A. sticticollis;* G, genital capsule of *Agalliopsis ballii;* H, genital capsule, and I, tip of aedeagus, of *A. fuscosignata;* J, genital capsule of *A. pepino* (×55); K, genital capsule of *A. conformis;* L, genital capsule, and M, tip of aedeagus, of *A. huachucae;* N, genital capsule, and O, tip of aedeagus, of *A. ancoralis;* P, genital capsule, and Q, tip of aedeagus, of *A. exilis;* R, genital capsule, and S, tip of aedeagus, of *A. variabilis.* Drawings of genital capsules are of the lateral view; drawings of aedeagi are of the dorsal view.

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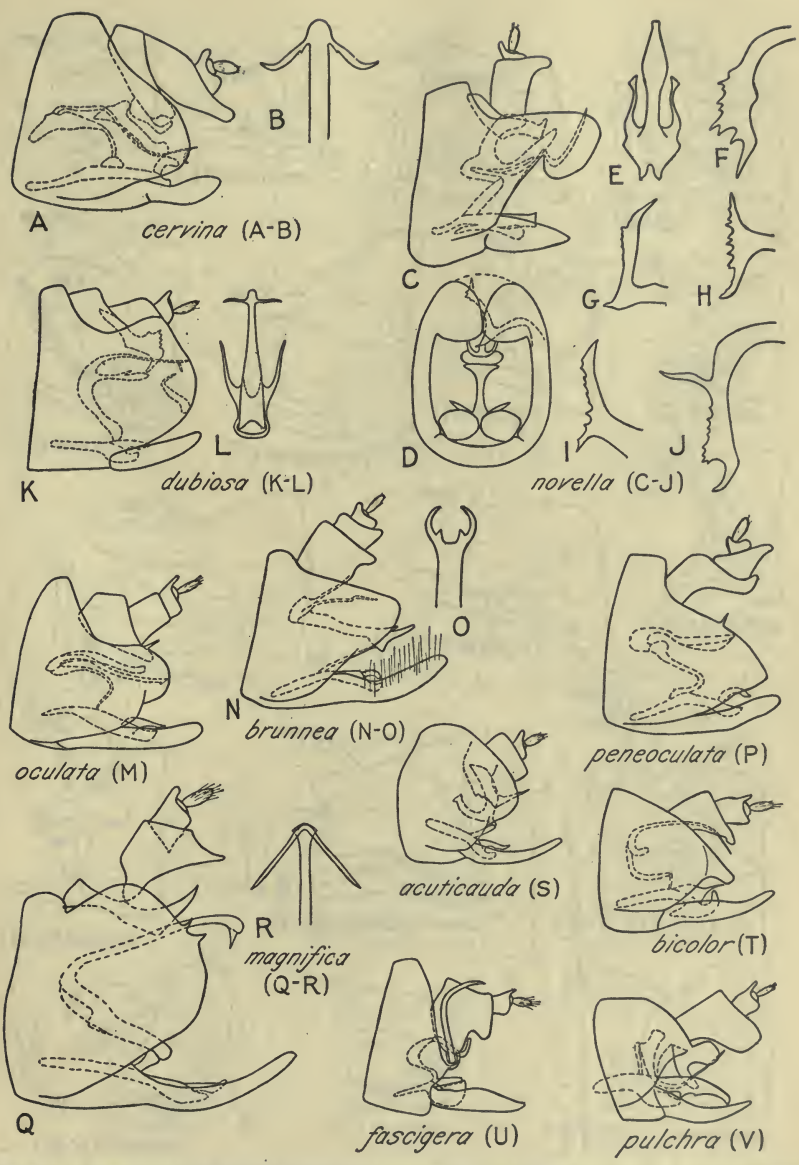

FIGURE 14.—Internal male genitalia of *Agalliopsis* and *Agallia* spp.: A, Genital capsule, and B, tip of aedeagus, of *Agalliopsis cervina;* C, genital capsule, D, caudal view of same, E, aedeagus, F, pygofer hook, of Colorado specimen, G, same of Washington, D.C., specimen, H, same of Texas specimen, I, same of Jamaican specimen, and J, same of Ontario, Canada, specimen, of *A. novella;* K, genital capsule, and L, aedeagus, of *A. dubiosa;* M, genital capsule of *A. oculata;* N, genital capsule, and O, tip of aedeagus, of *A. brunnea;* P, genital capsule of *A. peneoculata;* Q, genital capsule, and R, tip of aedeagus, of *A. magnifica;* S, genital capsule of *Agallia acuticauda;* T, genital capsule of *A. bicolor;* U, genital capsule of *A. fascigera;* V, genital capsule of *A. pulchra*. Drawings of genital capsules, except D, are of the lateral view; drawings of aedeagi are of the dorsal view; and drawings of pygofer hooks are of the caudal view of the right hook.

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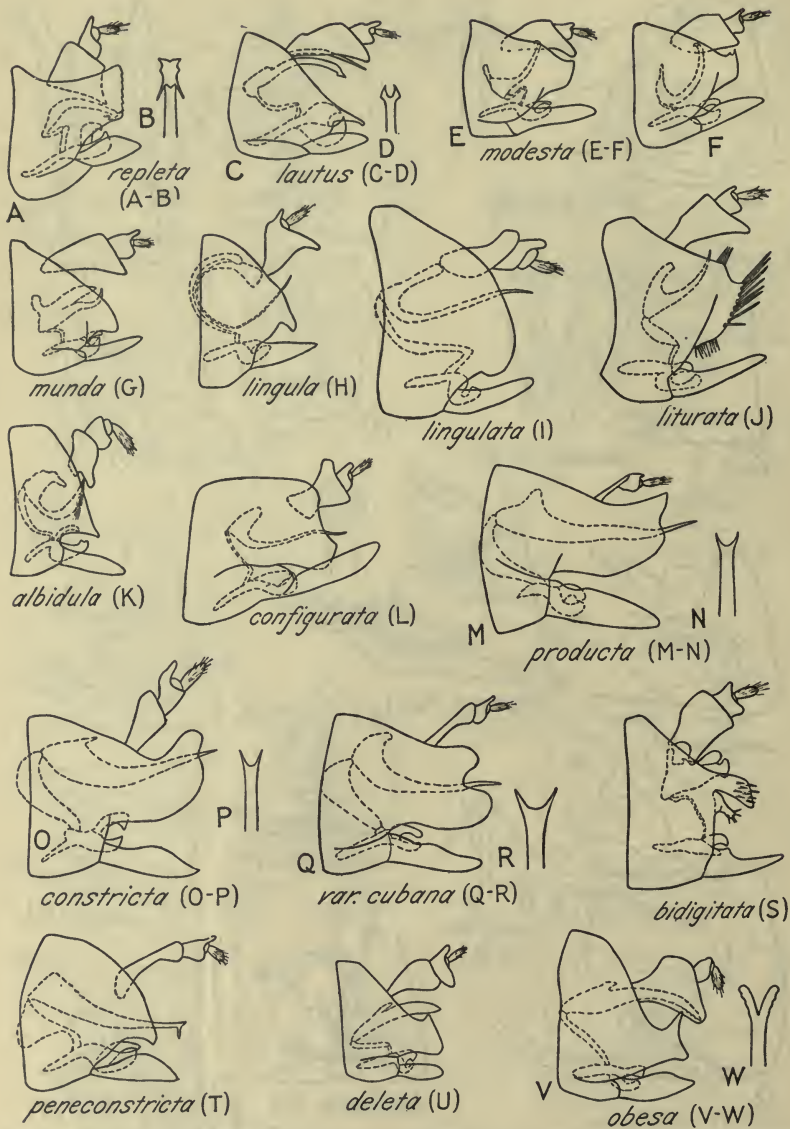

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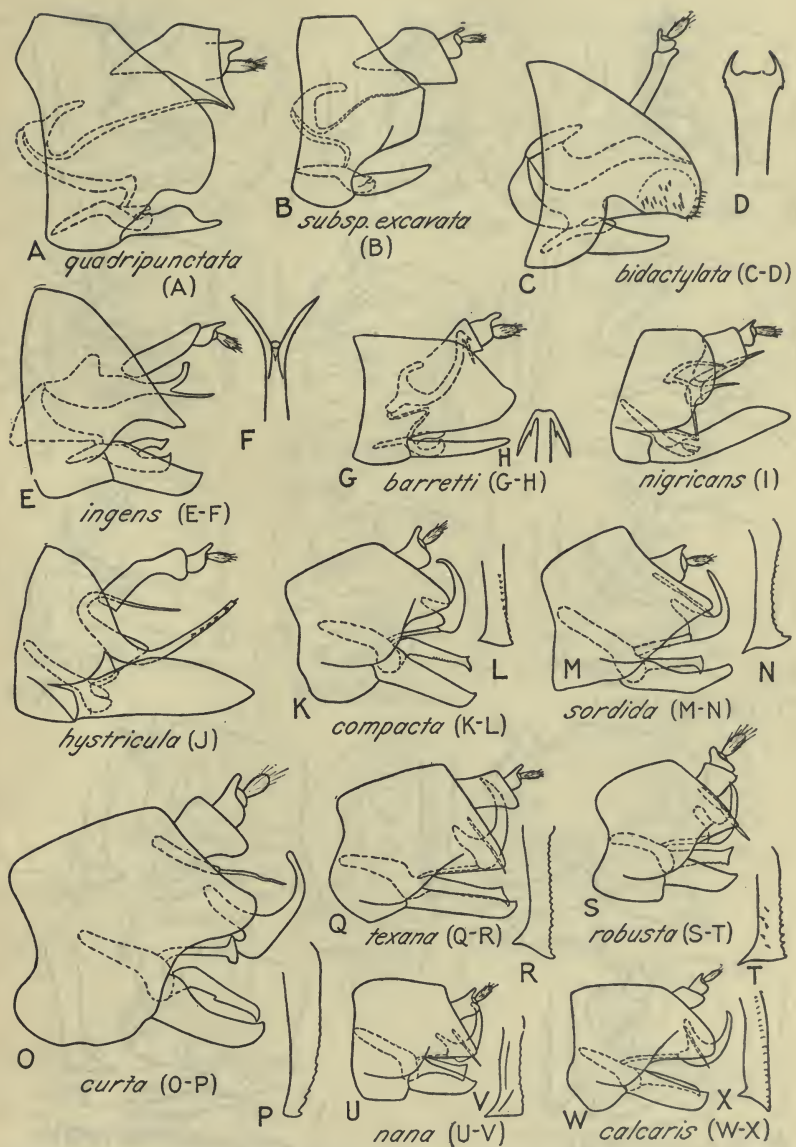

FIGURE 16.—Internal male genitalia of *Agallia* and *Aceratagallia* spp.: A, Genital capsule of *A. quadripunctata;* B, genital capsule of *A. quadripunctata* subsp. *excavata;* C, genital capsule, and D, tip of aedeagus, of *A. bidactylata;* E, genital capsule, and F, tip of aedeagus, of *A. ingens;* G, genital capsule, and H, caudal view of tip of aedeagus, of *A. barretti;* I, genital capsule of *A. nigricans;* J, genital capsule of *A. hystricula;* K, genital capsule, and L, style, of *Aceratagallia compacta;* M, genital capsule, and N, style, of *A. sordida;* O, genital capsule, and P, style, of *A. curta;* Q, genital capsule, and R, style, of *A. texana;* S, genital capsule, and T, style, of *A. robusta;* U, genital capsule, and V, style, of *A. nana;* W, genital capsule, and X, style, of *A. calcaris.* Drawings of genital capsules are of the lateral view, drawings of aedeagi, except H, are of the dorsal view, and drawings of styles are of the ventral view of the right style.

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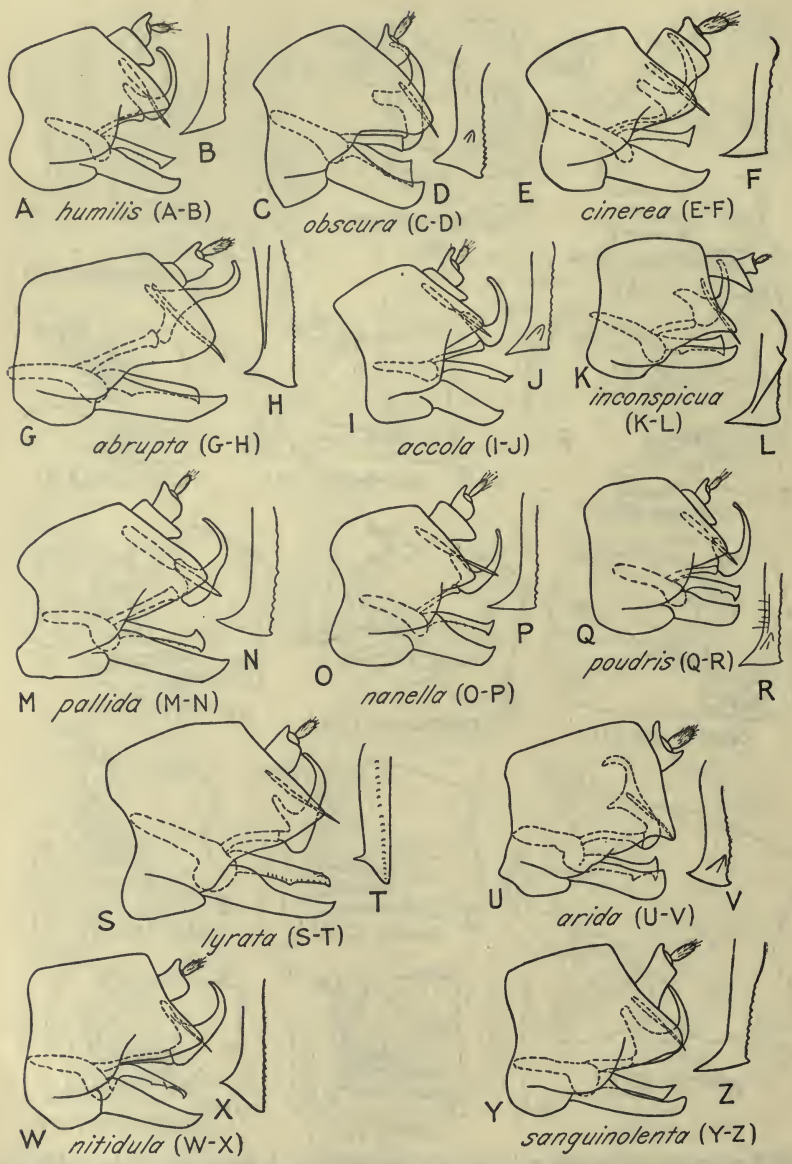

FIGURE 17.—Internal male genitalia of *Aceratagallia* spp.: A, Genital capsule, and B, style, of *A. humilis;* C, genital capsule, and D, style, of *A. obscura;* E, genital capsule, and F, style, of *A. cinerea;* G, genital capsule, and H, style, of *A. abrupta;* I, genital capsule, and J, style, of *A. accola;* K, genital capsule, and L, style, of *A. inconspicua;* M, genital capsule, and N, style, of *A. pallida;* O, genital capsule, and P, style, of *A. nanella;* Q, genital capsule, and R, style, of *A. poudris;* S, genital capsule, and T, style, of *A. lyrata;* U, genital capsule, and V, style of *A. arida;* W, genital capsule, and X, style, of *A. nitidula;* Y, genital capsule, and Z, style, of *A. sanguinolenta.* Drawings of genital capsules are of the lateral view, drawings of styles are of the ventral view of the right style.

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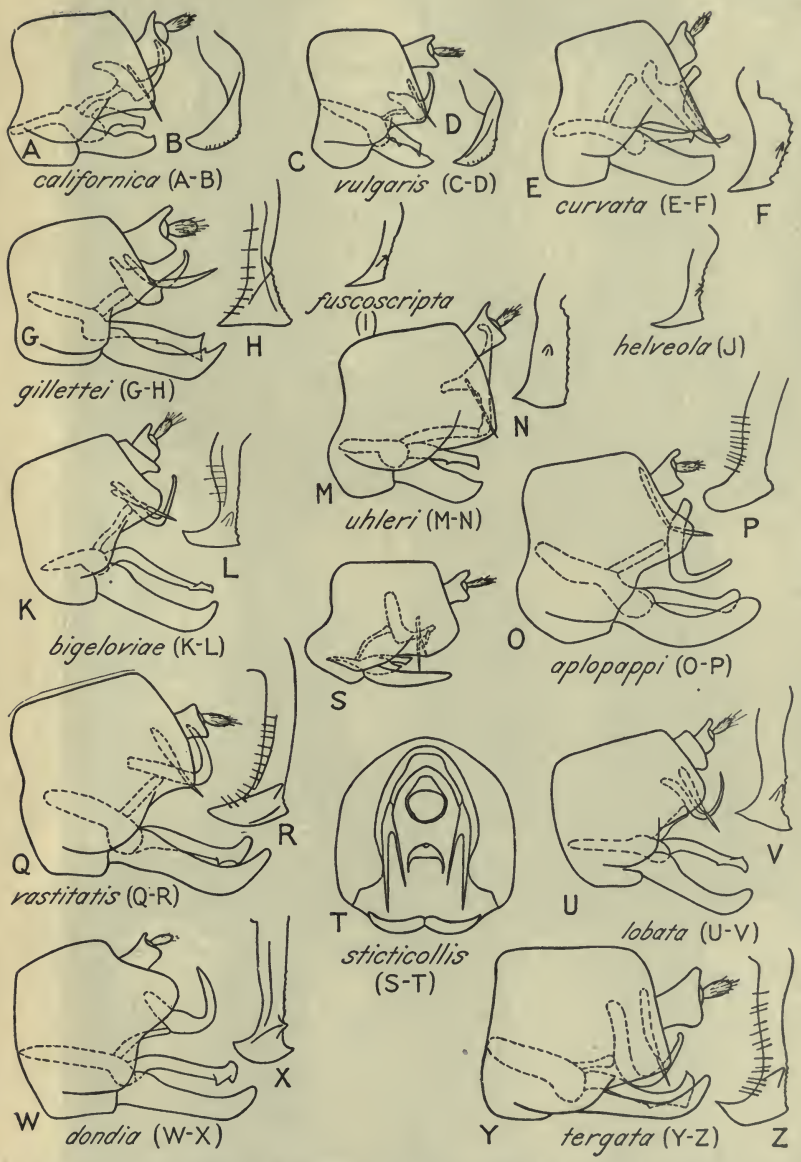

FIGURE 18.—Internal male genitalia of *Aceratagallia* spp. and *Agalliana sticticollis:* A, Genital capsule, and B, style, of *Aceratagallia californica;* C, genital capsule, and D, style, of *A. vulgaris;* E, genital capsule, and F, style, of *A. curvata;* G, genital capsule, and H, style, of *A. gillettei;* I, style of *A. fuscoscripta;* J, style of *A. helveola;* K, genital capsule, and L, style, of *A. bigeloviae;* M, genital capsule, and N, style, of *A. uhleri;* O, genital capsule, and P, style, of *A. aplopappi;* Q, genital capsule, and R, style, of *A. vastitatis;* S, genital capsule, and T, caudal view of same (×55), of *Agalliana sticticollis;* U, genital capsule, and V, style, of *Aceratagallia lobata;* W, genital capsule, and X, style of *A. dondia;* Y, genital capsule, and Z, style, of *A. tergata.* Drawings of genital capsules, except T, are of the lateral view, drawings of styles are of the ventral aspect of the right style.

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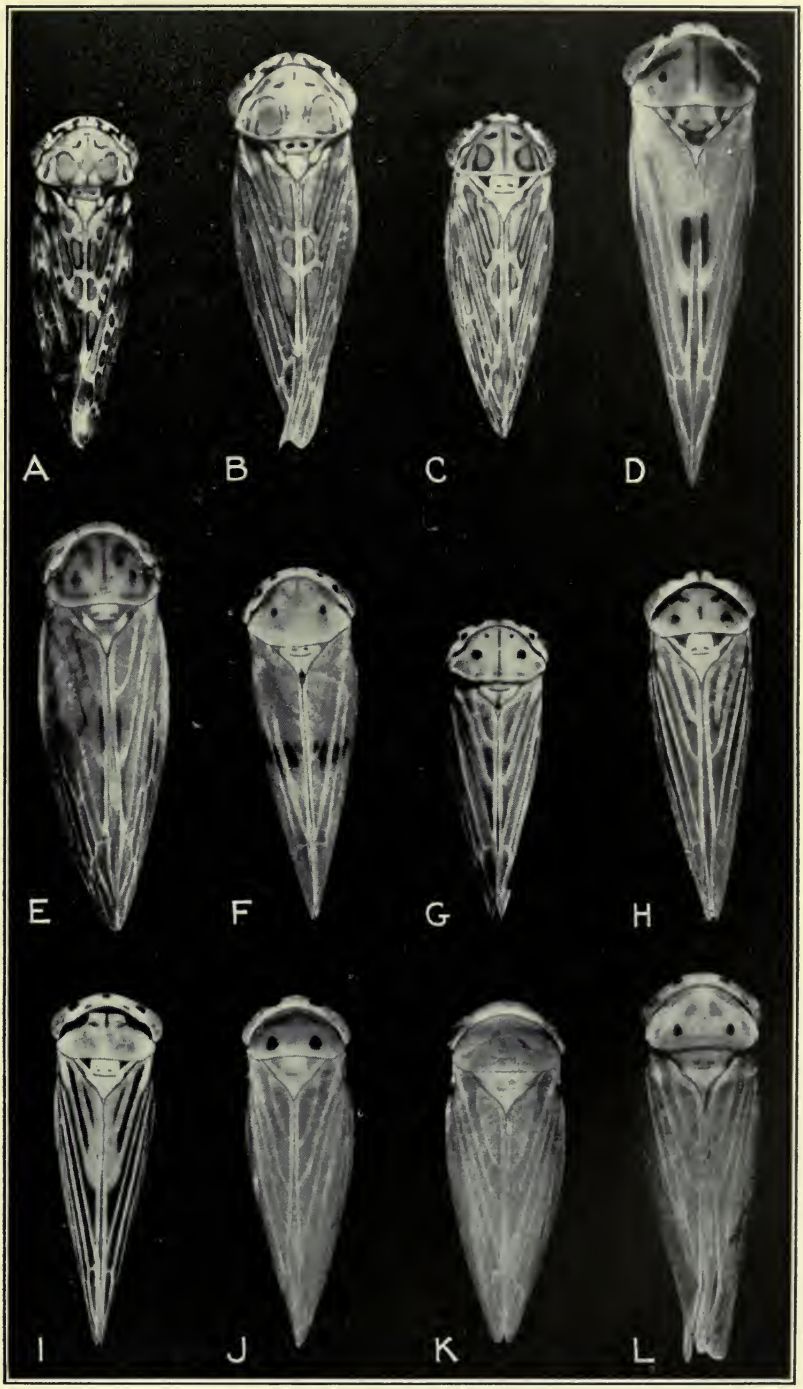

A, *Agalliopsis ballii;* B, *A. conformis;* C, *A. pepino;* D, *A. novella;* E, *A. variabilis;* F, *A. cincta;* G, *A. fuscosignata* var. *minor;* H, *Agallia repleta;* I, *A. pulchra;* J, *A. modesta;* K, *A. deleta;* L, *A. constricta.*

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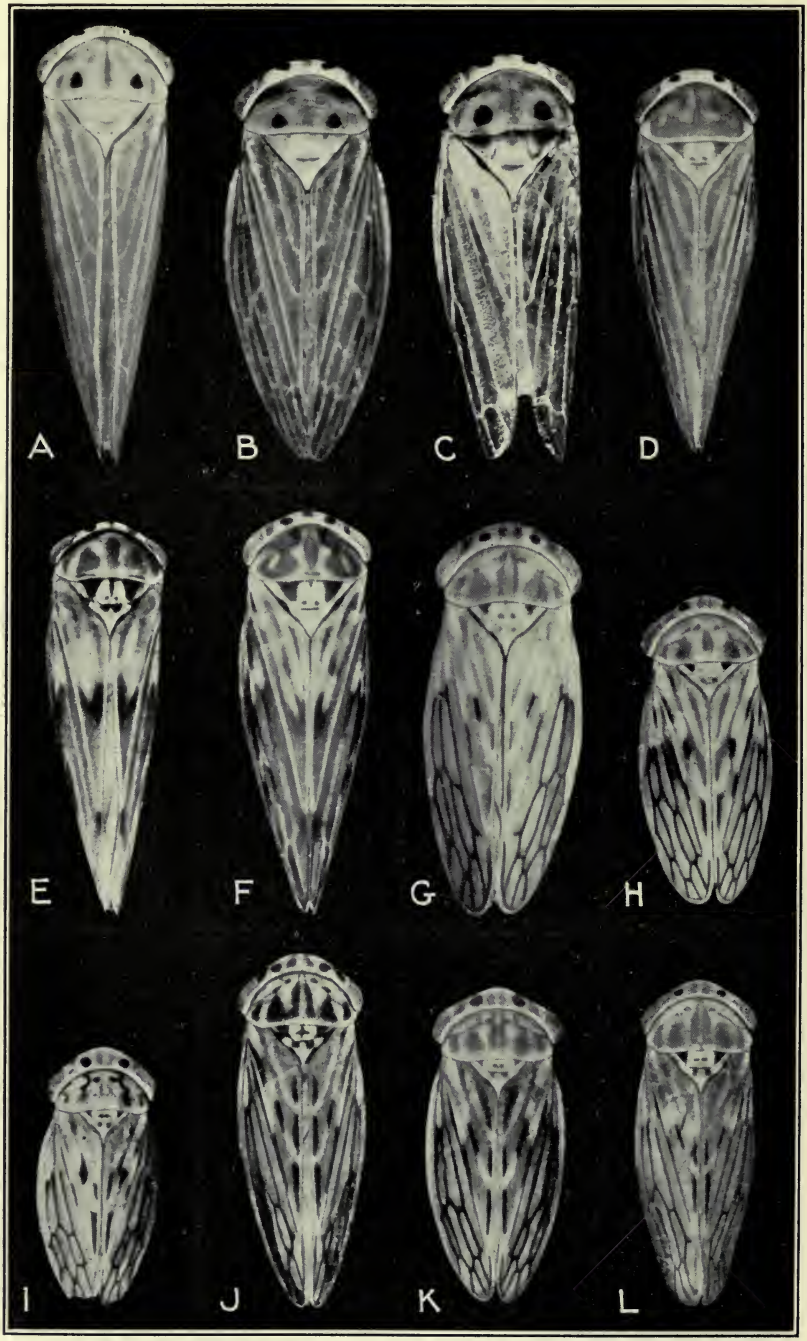

A, *Agallia producta;* B, *A. quadripunctata;* C, *A. lingulata;* D, *A. lingula;* E, *A. albidula;* F, *A. configurata;* G, *Aceratagallia dondia;* H, *A. aplopappi;* I, *A. bigeloviae;* J, *A. californica;* K, *A. sanguinolenta;* L, *A. gillettei.*

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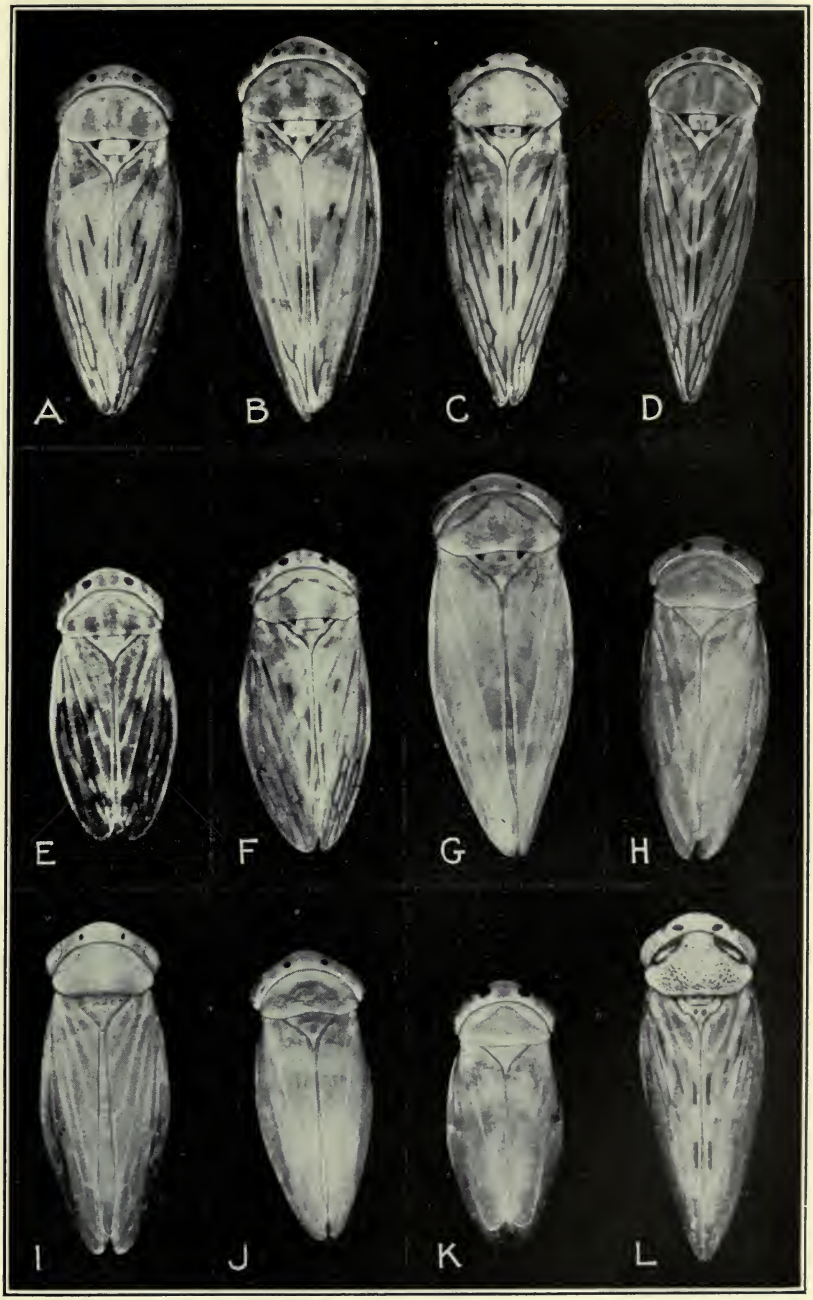

A, *Aceratagallia arida;* B, *A. obscura;* C, *A. calcaris;* D, *A. uhleri;* E, *A. compacta;* F, *A. vulgaris;* G, *A. curvata;* H, *A. nitidula;* I, *A. helveola;* J, *A. inconspicua;* K, *A. nana;* L, *Agalliana sticticollis.*

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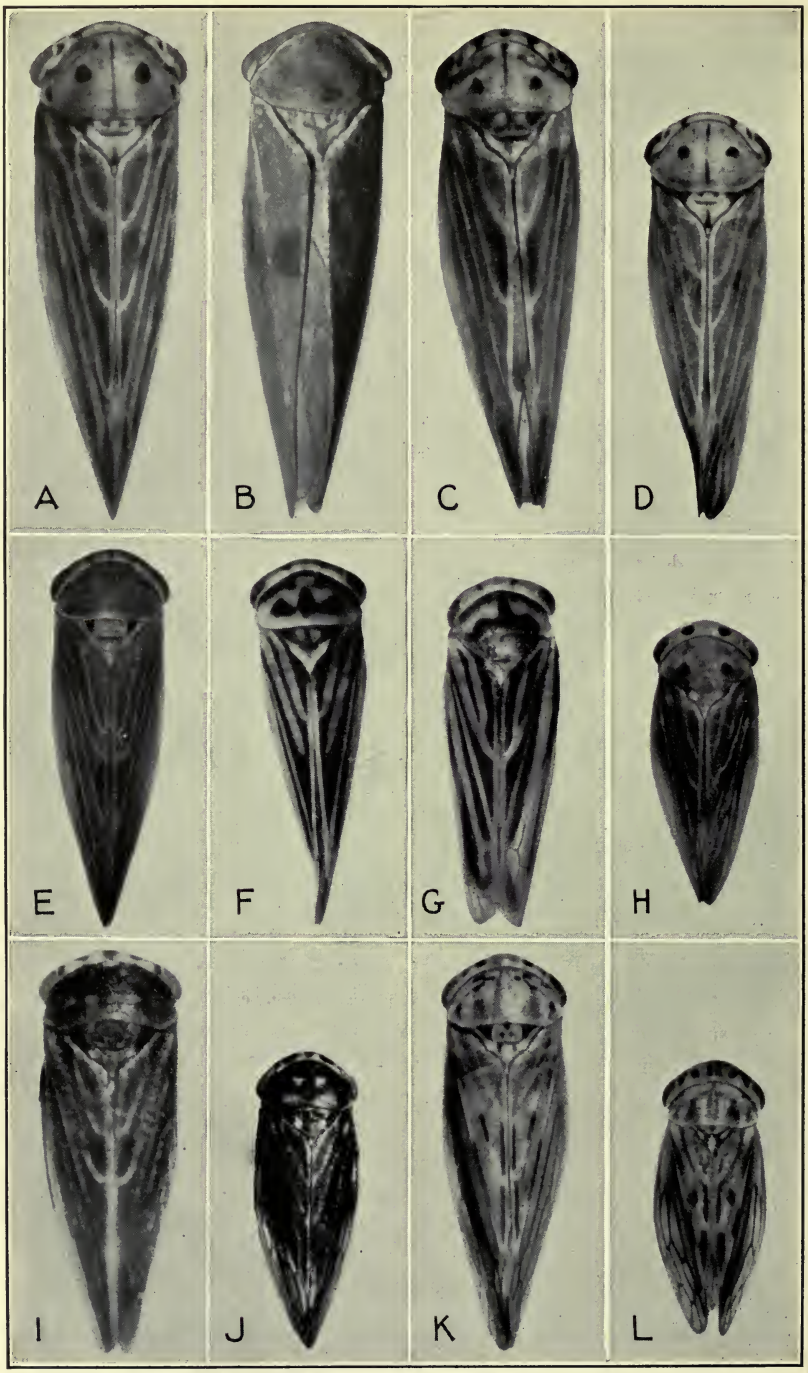

A, *Agalliopsis oculata;* B, *A. peneoculata;* C, *A. huachucae;* D, *A. fuscosignata;* E, *Agallia acuticauda;* F, *A. bicolor;* G, *A. fascigera;* H, *A. obesa;* I, *A. barretti;* J, *A. nigricans;* K, *Aceratagallia lyrata;* L, *A. fuscoscripta.*

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TECHNICAL BULLETIN No. 373 OCTOBER 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

STUDIES OF FLUORINE COMPOUNDS FOR CONTROLLING THE CODLING MOTH

By E. J. NEWCOMER, *senior entomologist, Division of Fruit and Shade Tree Insects, Bureau of Entomology,* and R. H. CARTER, *associate chemist, Insecticide Division, Chemical and Technological Research, Bureau of Chemistry and Soils* [1]

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INTRODUCTION

In the search for insecticidal materials which could be substituted for lead arsenate for the control of the codling moth, the Bureau of Entomology and the Bureau of Chemistry and Soils have studied a number of inorganic fluorine compounds. These compounds, because of their availability and chemical and physical properties, seem to offer a profitable field for investigation. This bulletin reports results of insecticidal tests made at the Yakima (Wash.) laboratory of the Bureau of Entomology. The experiments were all conducted under arid conditions. This fact is emphasized, as it is of special significance in interpreting the results obtained. Effective control or freedom from plant injury was not secured in similar experiments conducted under more humid conditions by other investigators of the Bureau of Entomology.

Our knowledge of the effect of fluorine compounds on human beings is limited. Available information, however, indicates that they are not more toxic than arsenic and that the fluorine residue on the fruit at harvest can be removed as easily as can either arsenic or lead residues. Information as to the removal of the metallic element of the fluorine compound is, however, not available.

[1] The writers are indebted to M. A. Yothers, associate entomologist, and F. P. Dean and A. R. Rolfs, junior entomologists, who assisted with many of the experiments

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The toxicity of certain fluorine compounds to insects has been recognized for some time, and a few of them have found wide application in the control of pests such as roaches, chicken lice, etc., where foliage injury is not a factor. One of the earliest references to the insecticidal properties of fluorine compounds is contained in British patent no. 8236, entitled "An Improved Composition or Material for Destroying Insects," issued to C. H. Higbee in 1896. During the last 15 years other fluorine compounds have been tested against a number of different insects infesting growing crops. In many instances good control has been reported. The records of these tests have been reviewed by Marcovitch (*9*),[2] who has also published a comprehensive bibliography.

OCCURRENCE AND AVAILABILITY OF FLUORINE COMPOUNDS

Fluorine does not occur free in nature, but it occurs in a wide variety of combinations with other elements throughout the earth's crust. Most phosphate-rock deposits contain 3 percent or more of fluorine; calcium fluoride in the form of fluorspar is a common material; and many other combinations of fluorine have a wide geographical distribution.

Many of the fluorine compounds are stable, chemically inert, finely crystalline or amorphous powders, and relatively insoluble. These qualities make them desirable from an insecticidal standpoint, as they can be applied by dusting or spraying; they adhere to foliage without being toxic to it, and they retain their efficiency over a considerable period of time. They are also nonirritating to operators and noninjurious to machinery.

HYDROFLUORIC AND HYDROFLUOSILICIC ACIDS

Two common acids containing fluorine are easily prepared from the naturally occurring compounds. When fluorspar or any other nonsiliceous fluoride is treated with sulphuric or other nonvolatile acid and the reaction mixture is heated, hydrogen fluoride distills off and may be dissolved in water to form aqueous hydrofluoric acid or condensed to the anhydrous hydrofluoric acid. Commercial aqueous hydrofluoric acid containing 48 percent HF is available in large quantitites. The reaction involved in its manufacture is expressed by the equation:

$$CaF_2+H_2SO_4 \longrightarrow CaSO_4+2HF$$

Phosphate rock contains a double compound of calcium phosphate and calcium fluoride and in addition silicon dioxide or sand, so that when this material is heated with sulphuric acid, as in the manufacture of phosphate fertilizer, reactions take place as follows: The calcium fluoride and sulphuric acid react to form hydrofluoric acid, which in turn reacts with the silica to form silicon tetrafluoride, which is evolved as a gas. These reactions are expressed by the equations:

$$CaF_2+H_2SO_4 \longrightarrow CaSO_4+2HF$$
$$4HF+SiO_2 \longrightarrow SiF_4+2H_2O$$

When the silicon tetrafluoride is passed into water, it combines with it to form hydrofluosilicic acid (H_2SiF_6).

$$3SiF_4+4H_2O \longrightarrow 2H_2SiF_6+Si(OH)_4$$

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

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Commercial aqueous hydrofluosilicic acid containing about 35 percent of H_2SiF_6 is available in large quantities. Each ton of phosphate rock contains the equivalent of about 75 pounds of hydrofluosilicic acid, and, since approximately 3,000,000 tons of phosphate rock are sold or used annually in the United States, there is an ample supply of fluorine. As gaseous silicon tetrafluoride is deleterious to vegetation, most fertilizer manufacturers are required to prevent its escape into the air; so any new use for this compound is welcomed.

FLUORIDES

The fluorides, or salts of hydrofluoric acid, are the most common commercial fluorine compounds. They are represented by the general formulas MF, MF_2, MF_3, etc., where M represents mono-, di-, and tri-basic elements, respectively. Fluorides of practically all the metals have been prepared and their properties studied. In general, they are finely crystalline compounds or almost amorphous powders, stable, and with widely differing solubilities in water (*2*). Their insecticidal properties have been investigated quite thoroughly, but usually if soluble enough to have the desired toxicity to insects these compounds cause foliage injury. Most fluorides are dense powders which are not suitable for dusting purposes and do not adhere well to foliage.

FLUOSILICATES

The fluosilicates, or salts of hydrofluosilicic acid, are another important class of fluorine compounds. They are also sold and advertised commercially as silicofluorides, but the American Chemical Society recognizes only the term "fluosilicate." They are represented by the general formulas M_2SiF_6, $MSiF_6$, $M_2(SiF_6)_3$, etc., where M represents mono-, di-, and tri-basic elements, respectively.

The fluosilicates of most of the metals have been prepared and their properties determined. They are finely crystalline or amorphous powders or well-defined crystalline compounds, some with and some without water of crystallization. They are usually much more soluble than the corresponding fluorides (*2*, *4*), and in solution they give an acid reaction. Sodium fluosilicate, for example, reacts with water according to the equation:

$$3Na_2SiF_6+4H_2O \rightleftharpoons 6NaF+2H_2SiF_6+Si(OH)_4$$

The titration of the liberated acid in a fluosilicate solution with standard alkali is often employed as an analytical procedure:

$$Na_2SiF_6+4NaOH \longrightarrow 6NaF+SiO_2+2H_2O$$

There are only three fluosiliates whose solubility is low enough to permit of their use as insecticides on field crops. They are the fluosilicates of barium, potassium, and sodium. These compounds are available commercially both in the pure form and mixed with diluents to improve their physical condition for dusting purposes.

Sodium fluosilicate is available commercially in large quantities. It can be obtained easily in a high degree of purity, commercial samples in many cases showing by analysis a purity of more than 99 percent. In order to improve its physical condition for dusting purposes it is also mixed with diluents and sold as a dusting material. Diatomaceous earth, talc, silica, sulphur, hydrated lime, and other finely divided materials are used for this purpose.

Potassium fluosilicate is less soluble than sodium fluosilicate and has received less attention as an insecticide, probably on account of its

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greater cost. It is a white, very finely divided powder suitable for application by spraying or dusting. It can be obtained easily in a high state of purity and can be mixed with diluents similarly to sodium fluosilicate.

Barium fluosilicate is the least soluble of the fluosilicates. It is available commercially in large quantities either in the pure form or mixed with diluents, as in the case of sodium fluosilicate. A special light form claimed to contain 80 percent $BaSiF_6$ and 20 percent fluffing agent is also available. It is a white, very finely divided powder suitable for application by spraying or dusting, and it adheres well to foliage.

It should be remembered that all fluosilicates give an acid reaction in solution and that mixtures with basic materials such as hydrated lime react, neutralizing part of the fluosilicate, to form a fluoride. Barium fluosilicate in particular is also not compatible with nicotine sulphate, Bordeaux mixture, lime-sulphur, or spreaders containing a high percentage of calcium compounds, sodium sulphate, or other soluble sulphates.

FLUOALUMINATES

Other fluorine compounds that appear promising are the fluoaluminates, or salts of the hypothetical acid H_3AlF_6. If aluminum oxide or hydroxide is treated with hydrofluoric acid in excess, the aluminum fluoride first formed is soluble in the excess acid so that in effect we have a solution of H_3AlF_6:

$$Al(OH)_3+6HF \rightleftharpoons H_3AlF_6+3H_2O$$

Salts of this acid may be formed in the same way as with any other acid—viz, by treatment with a base or a solution of another more soluble salt.

The natural mineral cryolite, or sodium fluoaluminate, is an example of this class of compounds. It occurs in nature in well-defined crystalline form. The other alkali-metal salts of this class are described by Carter (*5*). Little has been published on the preparation and properties of the fluoaluminates of the other metals, but considerable work is now in progress.

In general, the fluoaluminates are finely crystalline or amorphous powders, stable, relatively insoluble, and since they are not easily hydrolyzed by water their solutions or suspensions in water are practically neutral. They should therefore be safe for use on field crops. These compounds are also stable in the presence of moisture and are not appreciably decomposed by hard water. However, they should not be mixed with lime-sulphur or other materials of high calcium content.

Synthetic cryolite, or sodium fluoaluminate, of a high degree of purity is available commercially. This is a white, very finely divided powder, relatively insoluble, and suitable for spraying and dusting purposes. Its refractive index is close to that of water, so that concentrations of 4 pounds to 100 gallons appear almost clear, although only a small percentage is really in solution. There is also available commercially a special form of natural cryolite, which is finely powdered, suspends well in water, and seems to be as suitable as the synthetic material.

Potassium fluoaluminate has been made commercially and is a white, finely crystalline or amorphous powder of low solubility,

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suitable for spraying purposes but not quite so suitable for dusting. Its dusting properties can probably be improved, however. The refractive index of this compound is likewise low, and suspensions of it are nearly transparent, but only a small percentage actually goes into solution.

ANALYSES OF MATERIALS USED

Most of the compounds used for the experimental work reported in this bulletin were analyzed to determine the percentage purity, and these analyses are given below:

	Percent
Barium fluosilicate no. 1:	
Barium fluosilicate ($BaSiF_6$)	74. 5
Other material	25. 5
Barium fluosilicate no. 2:	
Barium fluosilicate ($BaSiF_6$)	66. 5
Barium fluoride (BaF_2)	22. 4
Moisture	0. 2
Other material	10. 9
Barium fluosilicate no. 3:	
Barium fluosilicate ($BaSiF_6$)	95. 0
Inert ingredients	5. 0
Barium fluosilicate no. 4:	
Barium fluosilicate ($BaSiF_6$)	95. 4
Barium fluoride (BaF_2)	1. 5
Inert ingredients	3. 1
Barium fluosilicate no. 5:	
Barium fluosilicate ($BaSiF_6$)	74. 1
Barium fluoride (BaF_2)	2. 7
Undetermined (mostly silica)	23. 2
Potassium fluosilicate no. 1:	
Potassium fluosilicate (K_2SiF_6)	96. 7
Potassium fluoride (KF)	2. 7
Moisture	0. 2
Other material	0. 4
Sodium fluosilicate no. 1:	
Sodium fluosilicate (Na_2SiF_6)	98. 1
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	0. 6
Other material	1. 3
Potassium fluoaluminate no. 1:	
Potassium fluoaluminate (K_3AlF_6)	96. 6
Iron and aluminum oxides, etc. (Fe_2O_3 and Al_2O_3)	3. 4
Sodium fluoaluminate (synthetic cryolite) no. 1:	
Sodium fluoaluminate (Na_3AlF_6)	79. 8
Undetermined	20. 2
Sodium fluoaluminate (synthetic cryolite) no. 2:	
Sodium fluoaluminate (Na_3AlF_6)	91. 0
Alumina (Al_2O_3)	6. 0
Undetermined	3. 0

The fish oils employed were salmon oils, which are obtainable on the Pacific coast. The physical and chemical constants of two of these oils were determined:[3]

	No. 1	*No. 2*
Specific gravity at 15°/4° C	0. 922	0. 932
Viscosity, seconds, Saybolt Universal at 100° F	165	132
Saponification number	191	194
Unsulphonated residue (A.O.A.C. method)	None.	None.
Iodine number (Hanus)	125	180
Acetyl value, mg KOH per gram acetylated oil	24	12
Free fatty acids (calculated as oleic acid), percent	7. 5	. 7
Water-soluble acids (calculated as oleic acid), percent	. 14	. 08
Volatile fatty acid number, mg KOH per 5 g of oil	. 52	. 23
Insoluble fatty acids (Hehner), percent	96. 6	96. 1

[3] These analyses were made by F. E. Dearborn, of the Bureau of Chemistry and Soils.

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These constants correspond quite well with those given by Hood (*8*), except that sample no. 1 had a rather high free-fatty-acid content. No injury resulted from the use of this oil, however.

METHODS OF MAKING TESTS

Most of the laboratory experiments were made in the manner already used by Newcomer (*11*). Carefully selected apples of one variety were suspended by their stems in an outdoor shelter and sprayed or dusted uniformly with the material to be tested. When they were thoroughly dry, 10 newly hatched larvae were placed on each apple, five apples being used for each test. In 1929 and 1930 tests were also made in which larvae were placed on the fruit several days after it had been sprayed. In order to have the fruit in a normal condition, it was sprayed while hanging on the tree, and picked just before the larvae were placed on it. Care was taken to remove adjacent leaves, so that the spray material would not be rubbed off by them. In 1930, also, small pieces of paraffined paper on which were 10 eggs almost ready to hatch were attached to the stems by means of paper clips. The resulting larvae readily found their way to the apples.

The results of the laboratory experiments are given in terms of percentage of worms entering the fruit, percentage causing only stings, percentage causing total blemishes, and, in most instances, percentage of control. The last-mentioned figure has been obtained by the method of Abbott, Culver, and Morgan (*1, p. 6*), who used the following formula:

$$\frac{\text{(Percentage of worms entering fruit in check)} - \text{(percentage of worms entering treated fruit)}}{\text{(Percentage of worms entering fruit in check)}} \times 100 = \text{percent control}$$

Many of the experiments reported are averages of two or more tests made during the same season. When this was done, the same number of tests, made on the same dates, are used for each experiment in the table. No attempt has been made to compare one series of experiments with another, for variations due to differences in temperature and humidity, condition of the larvae, and variety and degree of ripeness of the fruit would make such a comparison of little or no value.

For the orchard experiments plots containing 8 to 16 trees were used. The spraying was done with a gasoline power sprayer maintaining 300 to 350 pounds pressure and using spray guns and two lines of hose. Very wormy orchards were selected for all the tests in order to give a fair comparison. Tests in which the infestation is less than 5 percent are not dependable, as experimental error may overshadow any differences caused by variations in the treatment.

The results of the orchard experiments are given in terms of percentage of fruit wormy, percentage stung, percentage of sound fruit—that is, fruit that is neither wormy nor stung—and ratio of stings to total blemishes. Fruit that was both wormy and stung is recorded under both beadings.

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LABORATORY EXPERIMENTS

EXPERIMENTS IN 1925 AND 1926

The first work done with fluorine compounds at Yakima, Wash., was in 1925, when a barium fluosilicate (no. 1) was available for laboratory experiments. It was tested at dilutions of 2 and 4 pounds to 100 gallons of water, without fish oil, in comparison with lead arsenate at 2 pounds to 100 gallons (table 1). The results were nearly as good as those obtained with lead arsenate.

TABLE 1.—*Toxic effect of barium fluosilicate, as compared with that of lead arsenate, on the larvae of the codling moth: Laboratory experiments, 1925*

[4 tests averaged for each experiment]

Experiment no.	Material [1]	Dilution (per 100 gallons)	Wormholes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes	Control
		Pounds	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
1	Barium fluosilicate no. 1	2	17	8.5	48	24.0	32.5	74.6
2	do	4	16	8.0	49	24.5	32.5	76.1
3	Lead arsenate	2	13	6.5	46	23.0	29.5	80.6
4	Check (unsprayed)	--------	67	33.5	42	21.0	54.5	--------

[1] Analyses of most of the fluorine compounds mentioned in this and following tables are given under Analyses of Materials.

In 1926 a sodium fluosilicate was tested, both as a spray and as a dust, being diluted with lime in the latter case, as indicated in table 2. The results were relatively poor.

TABLE 2.—*Toxic effect of sodium fluosilicate, as compared with that of lead arsenate, with and without the addition of hydrated lime, on the larvae of the codling moth: Laboratory experiments, 1926*

[4 tests averaged for each experiment]

Experiment no.	Material	Dilution (per 100 gallons)	Wormholes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes	Control
		Pounds	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
1	Sodium fluosilicate no. 1	2	80	40.0	21	10.5	50.5	31.0
2	do	4	60	30.0	28	14.0	44.0	48.3
3	Lead arsenate	2	35	17.5	29	14.5	32.0	69.8
		Percent[1]						
4	Sodium fluosilicate no. 1	16.7	38	19.0	18	9.0	28.0	67.2
	Hydrated lime	83.3						
5	Lead arsenate	15	9	4.5	26	13.0	17.5	92.2
	Hydrated lime	85						
6	Check (not sprayed or dusted)	--------	116	58.0	5	2.5	60.5	--------

[1] By weight.

EXPERIMENTS IN 1927

In 1927 the fluosilicates of barium, sodium, magnesium, and zinc and sodium fluoaluminate (synthetic cryolite) were tested at dilutions of 4 and 8 pounds per 100 gallons of water in comparison with lead arsenate at 2 and 4 pounds, respectively. The results obtained with the barium fluosilicate no. 2 and sodium fluosilicates were very good, as shown in table 3. The soluble zinc and magnesium fluosilicates were of little value. The zinc fluosilicate also caused the apples to

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turn brown wherever it entered the fruit through holes in the skin made by the codling-moth larvae. This suggests that it might burn the fruit and foliage if used in the orchard. The sodium fluoaluminate, which was rather impure and dense, did not give good control.

TABLE 3.—*Toxic effect of various fluorine compounds, as compared with that of lead arsenate, on the larvae of the codling moth: Laboratory experiments, 1927*

[2 tests averaged for each experiment]

Experiment no.	Material	Dilution (per 100 gallons)	Worm-holes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes	Control
		Pounds	*Number*	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
1	Barium fluosilicate no. 2	4	24	24	5	5	29	68.4
2	Sodium fluosilicate no. 1	4	31	31	11	11	42	59.2
3	Magnesium fluosilicate	4	57	57	4	4	61	25.0
4	Zinc fluosilicate	4	53	53	2	2	55	30.3
5	Sodium fluoaluminate no. 1	4	51	51	5	5	56	32.9
6	Lead arsenate	2	40	40	3	3	43	47.4
7	Barium fluosilicate no. 2	8	18	18	13	13	31	76.3
8	Sodium fluosilicate no. 1	8	17	17	11	11	28	77.6
9	Magnesium fluosilicate	8	46	46	4	4	50	39.5
10	Zinc fluosilicate	8	49	49	7	7	56	35.5
11	Sodium fluoaluminate no. 1	8	37	37	3	3	40	51.3
12	Lead arsenate	4	28	28	8	8	36	63.2
13	Check (unsprayed)	--------	76	76	0	0	76	--------

EXPERIMENTS IN 1928

It was thought that these materials might not adhere so well as lead arsenate, and therefore fish oil, in the quantity suggested by Hood (*8*) for use with lead arsenate, was added to them in the tests made in 1928. The degree of control obtained with all the fluorine compounds was higher than with lead arsenate, when compared with half the quantity of the latter, used without fish oil, as shown in table 4. This was in spite of the fact that the barium fluosilicate and sodium fluoaluminate were not very pure, being the same as were used in 1927. The addition of fish oil (no. 1) to the lead arsenate resulted in somewhat better control than was obtained with the fluorine compounds.

TABLE 4.—*Toxic effect of various fluorine compounds plus fish oil, as compared with that of lead arsenate, with and without the addition of fish oil, on the larvae of the codling moth: Laboratory experiments, 1928*

[3 tests averaged for each experiment]

Experiment no.	Material	Dilution (per 100 gallons)	Worm-holes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes	Control
			Number	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
1	Barium fluosilicate no. 2 Fish oil no. 1	4 pounds 1 pint	24	16.0	24	16.0	32.0	70.4
2	Potassium fluosilicate no. 1 Fish oil no. 1	4 pounds 1 pint	18	12.0	39	26.0	38.0	77.8
3	Sodium fluoaluminate no. 1 Fish oil no. 1	4 pounds 1 pint	25	16.7	23	15.3	32.0	69.1
4	Lead arsenate Fish oil no. 1	2 pounds 1 pint	16	10.7	35	23.3	34.0	80.2
5	Lead arsenate	2 pounds	30	20.0	31	20.7	40.7	63.0
6	Check (unsprayed)	----------	81	54.0	9	6.0	60.0	--------

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EXPERIMENTS IN 1929

The compounds tested in 1929 were the same as those used in 1928. Tests were made 1 day and 7 days after spraying. Inasmuch as it was necessary to spray the apples while they were still on the trees, it was impossible to spray them so evenly and thoroughly as when they can be revolved while being sprayed. However, the results are interesting (table 5). The barium fluosilicate gave, on the whole, slightly better control than the potassium fluosilicate, possibly because of better adhesive power. The sodium fluoaluminate was the best of the three in the 1-day test, but at the end of 7 days the control was not quite so good as with the other materials. In most instances the addition of fish oil improved the degree of control in the 1-day test, but this improvement was not evident in the 7-day test.

TABLE 5.—*Toxic effect of various fluorine compounds, as compared with that of lead arsenate, with and without the addition of fish oil, on the larvae of the codling moth: Laboratory experiments, 1929*

Experiment no.	Material	Dilution (per 100 gallons)	1 day after spraying				7 days after spraying			
			Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control	Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Barium fluosilicate no. 2	2 pounds	20	14	34	64.3	12	8	20	80.0
2	do Fish oil no. 1	do 1 pint	14	20	34	75.0	24	10	34	60.0
3	Barium fluosilicate no. 2	4 pounds	12	12	24	78.6	14	6	20	76.7
4	Potassium fluosilicate no. 1	2 pounds	24	20	44	57.1	24	8	32	60.0
5	do Fish oil no. 1	do 1 pint	12	30	42	78.6	32	6	38	46.7
6	Potassium fluosilicate no. 1	4 pounds	18	20	38	67.9	22	6	28	63.3
7	Sodium fluoaluminate no. 1	2 pounds	8	32	40	85.7	28	20	48	53.3
8	do Fish oil no. 1	do 1 pint	10	26	36	82.1	28	14	42	53.3
9	Sodium fluoaluminate no. 1	4 pounds	10	24	34	82.1	44	18	62	26.7
10	do Fish oil no. 1	do 1 pint	2	22	24	96.4	18	16	34	70.0
11	Lead arsenate	2 pounds	18	8	26	67.9	14	22	36	76.7
12	do Fish oil no. 1	do 1 pint	24	16	40	57.9	26	10	36	56.7
13	Check (unsprayed)		56	2	58	------	60	0	60	------

In an additional test made with sodium fluoaluminate and fish oil, the control was very good, as shown in table 6. This table also gives the results of a preliminary test with potassium fluoaluminate, which indicates that this compound may be of some value.

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TABLE 6.—*Toxic effect of sodium fluoaluminate and potassium fluoaluminate, as compared with that of lead arsenate, on the larvae of the codling moth: Laboratory experiments, 1929*

Experiment no.	Material	Dilution (per 100 gallons)	Wormholes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes	Control
			Number	*Percent*	*Number*	*Percent*	*Percent*	*Percent*
1	Sodium fluoaluminate no. 1 / Fish oil no. 1	2 pounds / 1 pint	4	8	21	42	50	81.0
2	Sodium fluoaluminate no. 1 / Fish oil no. 1	4 pounds / 1 pint	6	12	19	38	50	71.4
3	Lead arsenate	2 pounds	13	26	14	28	54	38.1
4	Check (unsprayed)		21	42	6	12	54	--------
5	Potassium fluoaluminate no. 1	do	24	48	10	20	68	38.5
6	Lead arsenate	do	26	52	6	12	64	33.3
7	Check (unsprayed)		39	78	0	0	78	--------

EXPERIMENTS IN 1930

Experiments were made in 1930 with barium fluosilicate and sodium fluoaluminate from several sources and with a series of 17 fluorine compounds prepared by Carter. The five fluorine compounds included in table 7, when used at the rate of 3 pounds to 100 gallons of water, with fish oil, all resulted in a control equal to or better than that with lead arsenate used at the rate of 2 pounds per 100 gallons, without fish oil. This was true both 1 day after spraying and 5 days after spraying.

TABLE 7.—*Toxic effect of various fluorine compounds, as compared with that of lead arsenate, with and without the addition of fish oil, on the larvae of the codling moth: Laboratory experiments, 1930*

[2 tests averaged for each experiment]

Experiment no.	Material	Dilution (per 100 gallons)	1 day after spraying				5 days after spraying			
			Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control	Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Barium fluosilicate no 2 / Fish oil no. 2	3 pounds / 1 quart	45.6	21.2	66.8	52.5	68.9	21.2	90.1	29.0
2	Barium fluosilicate no. 3 / Fish oil no. 2	3 pounds / 1 quart	53.3	22.3	75.6	44.5	68.4	22.3	90.7	29.5
3	Sodium fluoaluminate no. 1 / Fish oil no. 2	3 pounds / 1 quart	59.9	19.8	79.7	37.6	67.3	15.4	82.7	30.6
4	Sodium fluoaluminate no. 2 / Fish oil no. 2	3 pounds / 1 quart	40.0	31.0	71.0	58.3	47.1	34.8	81.9	51.4
5	Potassium fluoaluminate no. 1	2 pounds	76.0	11.0	87.0	20.8	73.5	14.3	87.8	24.2
6	do	3 pounds	57.5	15.2	72.7	40.1	73.9	17.1	91.0	23.8
7	do / Fish oil no 2	do / 1 quart	52.7	18.2	70.9	45.1	61.8	28.4	90.2	36.3
8	Potassium fluoaluminate no. 1	4 pounds	50.3	29.0	79.3	47.6	58.0	27.8	85.8	40.2
9	Lead arsenate	2 pounds	60.0	18.0	78.0	37.5	73.6	9.0	82.6	24.1
10	Check (unsprayed)		96.0	0	96.0	------	97.0	0	97.0	------

In another series of experiments a barium fluosilicate over 95 percent pure (no. 4) was compared with a material containing only about 74 percent barium fluosilicate (no. 5). The former material

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was somewhat better than the latter both 1 day and 5 days after application, as shown by comparing experiments nos. 1, 2, and 3 with nos. 4, 5, and 8 in table 8. Even when used at the rate of 4 pounds to 100 gallons (experiment no. 9), the compound containing 75 percent barium fluosilicate was not much better than the other material at 3 pounds. Variations in the method of using the fish oil were also tried. It was used without emulsification, and emulsified with the fluosilicate and with casein-lime spreader (experiments nos. 5, 6, and 7). No great difference in control resulted.

TABLE 8.—*Toxic effect of barium fluosilicate, as compared with that of lead arsenate, with and without the addition of fish oil or summer-oil emulsion, on the larvae of the codling moth: Laboratory experiments, 1930*

[2 tests averaged for each experiment]

Experiment no.	Material	Dilution (per 100 gallons)	1 day after spraying				5 days after spraying			
			Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control	Worms entering fruit	Worms causing stings	Worms causing total blemishes	Control
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Barium fluosilicate no. 4	3 pounds	60.7	19	79.7	35.4	59.5	10.1	69.6	26.4
2	do Fish oil no 2	do 1 quart	50.9	17.6	68.5	45.9	61	25	86	24.5
3	Barium fluosilicate no 4 Summer-oil emulsion	3 pounds 1 gallon	47.6	23.3	70.9	49.4	65.5	7	72.5	18.9
4	Barium fluosilicate no. 5	3 pounds	67	15	82	28.7	68.8	10	78.8	14.9
5	do Fish oil no. 2	do 1 quart	64.7	10.2	74.9	31.2	63.8	14.2	78	24
6	Barium fluosilicate no. 5 Fish oil no. 2, emulsified with the fluosilicate	3 pounds 1 quart	61.2	10.9	72.1	34.9	66.7	11.2	77.9	17.5
7	Barium fluosilicate no. 5 Fish oil no. 2, emulsified with casein lime spreader	3 pounds 1 quart	60	12	72	36.2	63.2	10.4	73.6	21.8
8	Barium fluosilicate no. 5 Summer-oil emulsion	3 pounds 1 gallon	58.4	13.4	71.8	37.9	73.2	4	77.2	9.4
9	Barium fluosilicate no. 5	4 pounds	55.3	19.3	74.6	41.2	59.4	7.1	66.5	26.5
10	Lead arsenate	2 pounds	65.6	9.7	75.3	30.2	71	8	79	12.1
11	Check (unsprayed)		94	1	95	------	80.8	0	80.8	------

The two sodium fluoaluminates (nos. 1 and 2) shown in table 9 were tested at the rate of 4 pounds to 100 gallons, with and without fish oil, and also with mineral oil and with a small quantity of mineral-oil emulsion. Unfortunately there was no unsprayed check with this series, so that the percentage of control cannot be given. However, by examining the percentage of worms entering the fruit and the percentage causing the total blemishes, as given in table 9, it will be evident that sodium fluoaluminate no. 2, which was the purer of the two, gave the better control. This was also shown in experiments nos. 3 and 4, table 7. It is apparent also that, with sodium fluoaluminate no. 2 at least, there is an advantage in adding a fish oil or mineral oil.

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TABLE 9.—*Toxic effect of sodium fluoaluminate, as compared with that of lead arsenate, with and without the addition of fish oil, summer oil, or summer-oil emulsion, on the larvae of the codling moth: Laboratory experiments, 1930*

Experiment no.	Material	Dilution (per 100 gallons)	Wormholes	Worms entering fruit	Stings	Worms causing stings	Worms causing total blemishes
			Number	*Percent*	*Number*	*Percent*	*Percent*
1	Sodium fluoaluminate no. 1	4 pounds	19	38	12	24	62
2	do Fish oil no. 2	do 1 quart	16	32	19	38	70
3	Sodium fluoaluminate no. 1 Summer-oil emulsion	4 pounds 1 quart	22	44	12	24	68
4	Sodium fluoaluminate no. 1 Summer oil	4 pounds 1 quart	23	46	11	22	68
5	Sodium fluoluminate no. 2	4 pounds	19	38	4	8	46
6	do Fish oil no. 2	do 1 quart	15	30	11	22	52
7	Sodium fluoaluminate no. 2 Summer-oil emulsion	4 pounds 1 quart	12	24	11	22	46
8	Sodium fluoaluminate no. 2 Summer oil	4 pounds 1 quart	17	34	4	8	42
9	Lead arsenate	2 pounds	34	68	5	10	78

In the tests made in 1930 fish oil was used at the rate of 1 quart to 100 gallons, instead of 1 pint. Analyses of apples sprayed with barium fluosilicate alone and with the addition of 0.5, 1, and 2 pints of fish oil (table 10) indicated that increasing the quantity of fish oil did not increase the quantity of barium fluosilicate placed on the apples but did increase the residue remaining after an interval of 10 days. Marcovitch and Stanley (*10*) had shown increased adhesiveness of barium fluosilicate during rains when fish oil was added. In this case a slight rain, amounting to 0.15 inch, occurred in the 10-day interval. Fish oil no. 2 was used in these tests.

TABLE 10.—*Effect of addition of different quantities of fish oil on adherence of barium fluosilicate*[1] *sprayed on apples*

Fish oil per 100 gallons of spray	Barium fluosilicate on apples		
	Sprayed in insectary; analyzed immediately	Sprayed in orchard	
		Analyzed immediately	Analyzed after 10 days
Pints	*Grain per pound*	*Grain per pound*	*Grain per pound*
None.	0.173	0.116	0.078
0.5	.093	.117	.080
1	.143	.119	.107
2	.197	.115	.114

[1] 4 pounds of barium fluosilicate used per 100 gallons.

The results of the toxicity tests (tables 5, 7, and 8) are not what would be expected from the analyses in table 10, the percentages of control decreasing about as much during the interval in the tests with fish oil as in those without it. Rain amounting to 0.3 inch fell during the interval of the test of 1929 and a smaller quantity fell during one of the two series of tests included in table 8, but no correlation between the rainfall and the results is evident. Further

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work is necessary before the value of the fish oil and the optimum quantity that should be used can be determined.

Table 11 gives tests of 17 fluorine compounds, all of which were laboratory preparations purified with a reasonable degree of care and may be considered as being at least 90 percent pure in all cases. Their solubilities were in every case less than that of sodium fluosilicate. The compounds were used at the rate of 4 pounds to 100 gallons, and compared with lead arsenate at the rate of 2 pounds to 100 gallons, no fish oil being used. In these tests five compounds—manganese fluoride, barium fluosilicate, potassium fluosilicate, magnesium fluoaluminate, and potassium fluoaluminate—were distinctly superior to lead arsenate, as indicated by the relative percentages of worms entering the fruit. Three others—sodium fluosilicate, ammonium fluoaluminate, and sodium fluoaluminate—were approximately equal to lead arsenate. Of these 8 compounds, 3—manganese fluoride, magnesium fluoaluminate, and ammonium fluoaluminate—had not been tried before.

TABLE 11.—*Toxic effect of various fluorine compounds and of lead arsenate on the larvae of the codling moth: Laboratory experiments, 1930*

Experiment no.	Material [1]	Worms entering fruit	Worms causing stings	Worms causing total blemishes
		Percent	*Percent*	*Percent*
1	Barium fluoride (BaF_2)	72	9	81
2	Lead fluoride (PbF_2)	61	15	76
3	Magnesium fluoride (MgF_2)	74	5	79
4	Manganese fluoride (MnF_2)	41	23	64
5	Barium fluosilicate ($BaSiF_6$)	42	32	74
6	Potassium fluosilicote (K_2SiF_6)	39	31	70
7	Sodium fluosilicate (Na_2SiF_6)	54	24	78
8	Ammonium fluoaluminate [$(NH_4)_3AlF_6$]	47	27	74
9	Barium fluoaluminate ($BaAlF_5$)	77	15	92
10	Calcium fluoaluminate ($CaAlF_5$)	66	15	81
11	Magnesium fluoaluminate ($MgAlF_5$)	39	31	70
12	Potassium fluoaluminate (K_3AlF_6)	33	37	70
13	Potassium fluoaluminate (K_3AlF_6)+SiO_2	50	23	73
14	Sodium fluoaluminate (Na_3AlF_6)	52	23	75
15	Sodium fluoaluminate (Na_3AlF_6)+SiO_2	74	9	83
16	Strontium fluoaluminate ($SrAlF_5$)	60	4	64
17	Zinc fluoaluminate ($ZnAlF_5$)	66	16	82
18	Lead arsenate ($PbHAsO_4$)	49	15	64

[1] The fluorine compounds were used at the rate of 4 pounds to 100 gallons and the lead arsenate at 2 pounds to 100 gallons. No fish oil was used.

The results of these laboratory experiments are somewhat variable, probably on account of the rather large experimental error which must exist in tests of this nature. Moreover, for the most part they show only the toxicity of the materials immediately after application. Nevertheless, they are valuable in giving preliminary indications of what may be expected from these compounds. The practical value of a new material can be determined only by orchard experiments. Such factors as durability of the material and its effect on the tree and the fruit do not enter into laboratory experiments.

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ORCHARD EXPERIMENTS

EXPERIMENTS IN 1926 AND 1927

In 1926 some dusting experiments were made in two orchards, in which a sodium fluosilicate dust was compared with a lead arsenate dust and with a lead arsenate spray. The same dilutions were used as in the laboratory tests (table 2, experiments nos. 3, 4, and 5). In one orchard the fluosilicate dust resulted in poorer control than the lead arsenate dust, and in the other orchard it was somewhat better. In both orchards the lead arsenate spray controlled the worms much better than either of the dusting treatments. Tests with barium fluosilicate and sodium fluosilicate used as sprays were made in 1927, but the crop on the trees used was so much smaller than that on the trees sprayed with lead arsenate that a fair comparison could not be made.

EXPERIMENTS IN 1928

In 1928 an orchard of Jonathan apple trees was selected that had not been sprayed the previous season and was therefore very heavily infested. The fluorine compounds were used at the rate of 4 pounds to 100 gallons, and compared with lead arsenate used at the rate of 2 pounds to 100 gallons. These fluorine compounds were made especially for the experiment, but they were quite dense, and the barium fluosilicate and sodium fluoaluminate were not especially pure. In order to increase the adhesiveness of the fluorine sprays, fish oil was added at the rate of 1 pint to 100 gallons. It was usually emulsified first with some of the fluorine compound, as suggested by Porter and Sazama (*12*). The crop was good, although somewhat smaller on the trees sprayed with fluorine compounds than on those sprayed with lead arsenate. Eight trees were used for each test, and the apples from the two most nearly uniform trees in each plot were examined.

As shown in table 12, the percentages of wormy apples on the trees sprayed with potassium fluosilicate and with sodium fluoaluminate were not materially higher than on the trees sprayed with lead arsenate, and the percentages of stung apples were somewhat lower; consequently a slightly larger percentage of the apples were sound. The barium fluosilicate was rather impure, and the results with it were poorer than when potassium fluosilicate was used.

TABLE 12.—*Effectiveness of various fluorine compounds, as compared with lead arsenate, in controlling the codling moth: Orchard experiments, 1928*

Test no.	Material [1]	Dilution (per 100 gallons)	Total apples	Wormy apples		Stung apples		Sound apples	Ratio of stings to total blemishes
		Pounds	*Number*	*Number*	*Percent*	*Number*	*Percent*	*Percent*	
1	Barium fluosilicate no. 2	4	2,698	718	26.6	524	19.4	59.1	0.40
2	Potassium fluosilicate no. 1	4	3,950	943	23.9	787	19.9	61.0	.45
3	Sodium fluoaluminate no. 1	4	4,348	1,006	23.1	873	20.1	62.1	.46
4	Lead arsenate	2	5,502	1,251	22.7	1,333	24.2	60.1	.49

[1] Fish oil, 1 pint to 100 gallons, used with all fluorine sprays.

Spray schedule: Calyx, May 10; first cover, May 22; second cover, June 1; third cover, June 12; fourth cover, June 22; fifth cover, July 11; sixth cover, Aug. 2.

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EXPERIMENTS IN 1929

In 1929 the same materials were used at the same dilutions. Carter (*3*) had shown that these compounds were compatible with lead arsenate. Therefore, a plot was added in which lead arsenate was used for the calyx and first cover sprays, followed by sodium fluoaluminate, and another one in which half the usual quantities of lead arsenate and sodium fluoaluminate were used together for the first four applications, followed by sodium fluoaluminate alone. These experiments were made in a different orchard from the one used in 1928; it consisted of Rome Beauty apple trees which had been poorly sprayed the previous season and were consequently heavily infested. The fruit on the various trees in the orchard was nearly uniform. Each plot contained 12 trees, and the fruit from 5 of these was examined in each test.

The results of these experiments are given in table 13. As in 1928, the barium fluosilicate was poor in effectiveness. When potassium fluosilicate and sodium fluoaluminate (synthetic cryolite) were used, the percentage of wormy fruit was similar to that when lead arsenate was used, and the number of stung fruit was markedly smaller. The use of sodium fluoaluminate following lead arsenate (test no. 4) gave the lowest percentage of wormy apples but a higher percentage of stung apples than when sodium fluoaluminate was used throughout. The combination of lead arsenate and sodium fluoaluminate is not included in the table, as the portion of the orchard in which it was used happened to be particularly wormy, and therefore this treatment cannot be compared with the other treatments. There was no evidence of injury to foliage or fruit in any of the plots.

TABLE 13.—*Effectiveness of various fluorine compounds, as compared with lead arsenate, in controlling the codling moth: Orchard experiments, 1929*

Test no.	Material [1]	Dilution (per 100 gallons)	Total apples	Wormy apples		Stung apples		Sound apples	Ratio of stings to total blemishes
		Pounds	*Number*	*Number*	*Percent*	*Number*	*Percent*	*Percent*	
1	Barium fluosilicate no. 2	4	10,671	4,174	39.1	2,287	21.4	50.3	0.30
2	Potassium fluosilicate no. 1	4	12,257	3,025	24.7	2,777	22.7	59.4	.46
3	Sodium fluoaluminate no. 1	4	12,664	3,825	30.2	3,196	25.2	53.4	.43
4	Lead arsenate in calyx and first cover spray	2	10,434	2,184	20.9	2,870	27.5	59.4	.56
	Sodium fluoaluminate no. 1 in remaining cover sprays	4							
5	Lead arsenate	2	12,749	3,247	25.5	4,598	36.1	50.7	.56

[1] Fish oil, 1 pint to 100 gallons, used with all fluorine sprays.

Spray schedule: Calyx, May 20; first cover, June 1; second cover, June 12; third cover, June 24; fourth cover, July 12; fifth cover, Aug. 10.

EXPERIMENTS IN 1930

In 1930 a barium fluosilicate mixture that had been made especially for insecticidal purposes (no. 5) was used. It contained about 74 percent barium fluosilicate, a percentage somewhat higher than that of the material used in 1928 and 1929. It was much lighter and remained in suspension better, owing to the inert material added. The orchard used in 1930 had been heavily infested and consisted of alternating double rows of Jonathan and Winesap apples, making it possible to include both varieties in each plot. Three series of

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tests were made, in all of which lead arsenate was used for the calyx and first cover sprays.

In the second to the sixth cover sprays barium fluosilicate was used except for two applications in one series (C), where mineral-oil emulsion plus nicotine sulphate was substituted for the fluosilicate. In another series (A) mineral-oil emulsion was added to the barium fluosilicate in two applications. Fish oil (no. 2) was added to the barium fluosilicate except when the mineral-oil emulsion was used. Comparable adjacent plots sprayed with lead arsenate were provided. The treatments for all these plots are given in table 14.

TABLE 14.—*Spray schedule used in orchard experiments for control of the codling moth, 1930*

Series	Test no.	Calyx (May 1) and first cover (May 22)	Second cover, June 4	Third cover, June 14
A	1	Lead arsenate 3 pounds [1]	Barium fluosilicate 3 pounds + 0.75 percent oil emulsion.	Barium fluosilicate [2] 4 pounds.
	2	do	Lead arsenate 2 pounds + 0.75 percent oil emulsion.	Lead arsenate 2 pounds.
	3	do	Lead arsenate 2 pounds	Do.
B	1	do	Barium fluosilicate 4 pounds	Barium fluosilicate 4 pounds.
	2	do	Lead arsenate 2 pounds	Lead arsenate 2 pounds.
C	1	do	0.75 percent oil emulsion + nicotine sulphate (1-1,200).	Barium fluosilicate 4 pounds.
	2	do	do	Lead arsenate 2 pounds.

Series	Test no.	Fourth cover, June 26	Fifth cover, July 20	Sixth cover, Aug. 12
A	1	Barium fluosilicate 4 pounds	Barium fluosilicate 3 pounds + 0.75 percent oil emulsion.	Barium fluosilicate 4 pounds.
	2	Lead arsenate 2 pounds	Lead arsenate 2 pounds + 0.75 percent oil emulsion.	Lead arsenate 2 pounds.
	3	do	Lead arsenate 2 pounds	Do.
B	1	Barium fluosilicate 4 pounds	Barium fluosilicate 4 pounds	Barium fluosilicate 4 pounds.
	2	Lead arsenate 2 pounds	Lead arsenate 2 pounds	Lead arsenate 2 pounds.
C	1	Barium fluosilicate 4 pounds	0.75 percent oil emulsion + nicotine sulphate (1-1,200).	Barium fluosilicate 4 pounds.
	2	Lead arsenate 2 pounds	do	Lead arsenate 2 pounds.

[1] Weights of barium fluosilicate and lead arsenate are for each 100 gallons of spray.
[2] Fish oil, 1 pint to 100 gallons, was used with all barium fluosilicate sprays except where oil emulsion was used.

In order to minimize the variation due to field heterogeneity, the schedule of barium fluosilicate and oil emulsion and the comparable schedules of lead arsenate, with and without oil emulsion, were repeated four times in the orchard, an arrangement similar to the Latin square being used. Owing to the number of experiments being made, it was not possible to do this with the other schedules. In each plot the fruit from two trees of each variety was examined. The results of all these experiments are given in table 15. In each case the percentages of wormy fruit in the comparable plots are similar, and the percentage of stung fruit is considerably more in the plots sprayed with lead arsenate; consequently the percentage of sound apples is lower than in the plots sprayed with fluosilicate.

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TABLE 15.—*Effectiveness of sprays of barium fluosilicate, as compared with lead arsenate, in controlling the codling moth: Orchard experiments, 1930* [1]

Series	Test no.	Material	Total apples	Wormy apples		Stung apples		Sound apples	Ratio of stings to total blemishes
			Number	*Number*	*Percent*	*Number*	*Percent*	*Percent*	
A	1	Barium fluosilicate (no. 5)+oil emulsion	38,138	4,405	11.5	3,043	8.0	81.8	0.39
	2	Lead arsenate+oil emulsion	28,505	3,122	10.9	3,324	11.7	79.5	.52
	3	Lead arsenate	28,909	3,419	11.8	3,733	12.9	77.7	.52
B	1	Barium fluosilicate no. 5	9,783	972	9.9	733	7.5	83.8	.41
	2	Lead arsenate	7,836	817	10.4	941	12.0	79.6	.53
C	1	Barium fluosilicate no. 5; oil emulsion+nicotine sulphate	8,576	895	10.4	649	7.6	83.3	.40
	2	Lead arsenate	9,942	1,121	11.3	1,082	10.9	79.7	.48

[1] Sprays were applied according to the schedule given in table 14.

TABLE 16.—*Effectiveness of fluorine compounds, as compared with that of lead arsenate, in orchard experiments for controlling the codling moth*

EXPERIMENTS IN 1929

Experiment no.	Treatment	Trees	Wormy apples			Stung apples		
			Weighted mean	Increase (+) or decrease (−) as compared with lead arsenate treatment	Difference divided by error	Weighted mean	Increase (+) or decrease (−) as compared with lead arsenate treatment	Difference divided by error
			Percent	*Percent*		*Percent*	*Percent*	
1	Barium fluosilicate	5	39.1±0.8	+13.6±1.5	9.1	21.4±0.6	−14.7±1.6	9.2
2	Potassium fluosilicate	5	24.7±0.9	−.8±1.6	.5	22.7±0.7	−13.4±1.7	7.9
3	Sodium fluoaluminate	5	30.2±1.1	+4.7±1.7	2.8	25.2±0.7	−10.9±1.7	6.4
4	Lead arsenate followed by sodium fluoaluminate	5	20.9±0.8	−4.6±1.5	3.1	27.5±1.2	−8.6±1.9	4.5
5	Lead arsenate	6	25.5±1.3			36.1±1.5		

EXPERIMENTS IN 1930

1	Barium fluosilicate + oil emulsion	16	11.8±0.9	+0.9±1.4	0.6	8.0±0.3	−3.7±1	3.7
2	Lead arsenate + oil emulsion	14	10.9±1.1			11.7±0.9		

Most of the comparable experiments made from 1928 to 1930 showed a slightly lower percentage of wormy fruit in the plots sprayed with lead arsenate than in those sprayed with the fluorine compounds, and it is desirable to know whether or not this difference is significant. This cannot be figured in some instances owing to the small number of trees examined. However, the significance of the differences in the treatments used in 1929 and 1930 may be determined from the statistical constants computed by the use of standard methods. The probable errors for individual plots were computed by the formula

$$P.E. = \pm 0.6745\sqrt{\frac{\Sigma pd^2}{p(n-1)}}$$

(p = the number of apples in each tree or plot), which is applicable to a weighted mean. This formula was used because of variations in

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the numbers of apples borne on the trees on which individual counts were made. The probable errors of the differences between plots were computed by the formula

$$E_{\text{diff.}} = \pm \sqrt{e_1^2 + e_2^2}$$

The results of these computations are given in table 16. If four times the probable error is used as a criterion, the differences in percentages of wormy apples are not significant except in the case of the barium fluosilicate used in 1929. On the other hand, the differences noted in the percentages of apples stung are significant in the comparisons in which the fluorine compounds were used throughout the

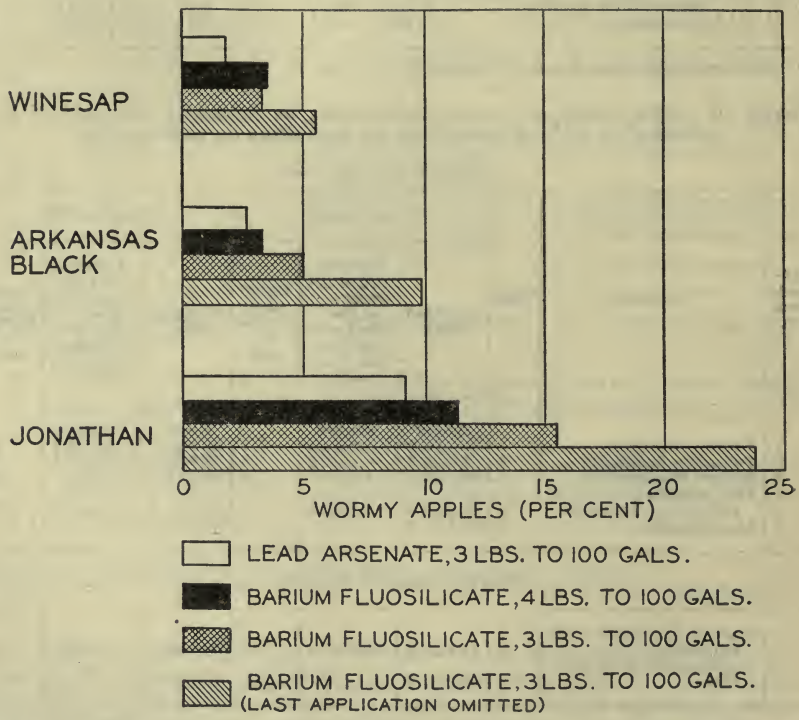

FIGURE 1.—Relative susceptibility of Winesap, Arkansas Black, and Jonathan apples to codling-moth infestation when sprayed with lead arsenate and with barium fluosilicate as shown by percentage of wormy fruit, 1930.

season, and doubtfully so in the comparisons in which the fluorine compound was used following a calyx and first cover spray of lead arsenate. It may be concluded, therefore, that under the conditions of these experiments the fluorine compounds are as effective as lead arsenate in preventing insects from infesting the fruit and that they are somewhat more effective in preventing insects from stinging it.

In 1930 two fruit growers also tested the effectiveness of barium fluosilicate as compared with lead arsenate. Apples from a number of trees in each orchard were examined. The results, which are given in table 17, are similar to those obtained in the writers' experiments, the percentage of wormy fruit being slightly higher and the percentage of stung fruit lower when barium fluosilicate was used. The results

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given in this table are from Jonathan and Rome Beauty apples in the first orchard (A) and from Jonathan apples in the second (B). In the latter orchard Arkansas Black and Winesap apple trees were also sprayed. The difference in the susceptibility of the three varieties is shown in figure 1. The last application of barium fluosilicate was omitted from some of the trees, and the increase in wormy apples on these trees was very marked. It should be noted that in this orchard the lead arsenate was used at the rate of 3 pounds to 100 gallons throughout the season, so that the barium fluosilicate had a more severe test than it had in the other experiments.

TABLE 17.—*Comparative effectiveness of barium fluosilicate and lead arsenate for controlling the codling moth, as shown by growers' orchard experiments, 1930*

Test no.	Material	Dilution (per 100 gallons)	Total apples	Wormy apples		Stung apples		Sound apples	Ratio of stings to total blemishes
			Number	*Number*	*Percent*	*Number*	*Percent*	*Percent*	
ORCHARD A									
1	Lead arsenate calyx and fourth cover sprays.	2 pounds	5,357	1,094	20.4	776	14.5	69.1	0.39
	Barium fluosilicate no. 5	4 pounds							
	Fish oil, first 3 cover sprays.	1 pint							
2	Lead arsenate calyx and 4 cover sprays.	2 pounds	4,523	840	18.6	875	19.3	66.7	.51
ORCHARD B									
1	Lead arsenate calyx and first cover sprays.	3 pounds	11,347	1,761	15.5	669	6.2	79.6	0.27
	Barium fluosilicate no. 5	do							
	Fish oil, .4 subsequent cover sprays.	1 pint							
2	Lead arsenate calyx and first cover sprays.	3 pounds	12,542	1,431	11.4	759	6.0	83.7	.34
	Barium fluosilicate no. 5	4 pounds							
	Fish oil, 4 subsequent cover sprays.	1 pint							
3	Lead arsenate, all sprays	3 pounds	14,771	1,367	9.2	857	5.8	85.8	.38

EFFECT OF FLUORINE COMPOUNDS ON FOLIAGE AND FRUIT

The possibility of injury to fruit or foliage has been considered. No foliage injury has been noted in the arid climate prevailing in the Yakima Valley, except a very little in 1927. The rainfall during the early part of September of that year was heavier than usual, and about 2 percent of the foliage sprayed with barium and sodium fluosilicate was injured. However, foliage sprayed with lead arsenate was also injured that year. All the experiments have been with apple trees, but some pear foliage has been sprayed without any injury.

There has been no apparent effect on the quality, size, or coloring of the fruit. Records have been kept of the average number of apples per box from all the trees examined. Three plots sprayed with fluorine compounds averaged 141 ± 1.3 apples per box, and three comparable plots sprayed with lead arsenate averaged 139 ± 2.5 apples per box. The difference, 2 ± 2.8, is not significant.

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ACCUMULATION AND ADHERENCE OF SPRAY MATERIALS

During the summer of 1930 an attempt was made to determine the quantities of material applied by the different treatments as well as the quantities of residue remaining on the fruit over a period of time.

Samples of Winesap apples sprayed with barium fluosilicate (no. 5) in the regular orchard tests were taken before and after each spraying and analyzed for residues. No standard procedure was available as in the case of arsenical residues; so a method was developed (*6*). Briefly, the method consisted of washing samples of fruit taken before and after each spray with boiling 3 percent sodium hydroxide solution and then analyzing this solution for barium by standard procedure and calculating to barium fluosilicate. Duplicate samples of apples that had received very different treatments were selected and, judging by the agreement between the duplicate analyses, the method seemed to be fairly accurate and gave consistent results. However, it was applicable only to the barium compound.

The results, calculated in milligrams per apple and in milligrams per square centimeter of surface, are given in table 18, and are compared with similar analyses of fruit sprayed throughout with lead arsenate. The surface area was calculated in each case from the average weight of the apples. The volume was first obtained by multiplying the weight by 1.2, as the ratio of weight to volume in Winesap apples was found to be 1 to 1.2. It was determined that a sufficiently accurate estimate of the surface area could be obtained by treating the apples as spheres, and therefore the area was obtained in this way:

$$S=\sqrt[3]{36\pi V^2}=4.84\sqrt[3]{V^2}$$

in which S is surface area and V is volume in corresponding units.

Spray residues on harvested fruit are ordinarily given in terms of grains per pound of fruit. In order that the residues occurring on this fruit at harvest may be directly compared with other residues, the number of grains per pound should be stated, and are as follows: Series B, test 1, 0.124; series A, test 1, 0.152; series A, test 2, 0.089. It should be kept in mind that the barium fluosilicate found is about 74 percent of the total residue, while the arsenious oxide present is only about 28.5 percent of the total lead arsenate residue. In table 18 there are several discrepancies in the quantities of residue before and after certain sprays. This is probably due to variations in the fruit used or to errors of analysis, and these figures are given only as an indication of what residues may be expected.

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TABLE 18.—*Comparison of barium fluosilicate and arsenious oxide residues on apples following spraying experiments, 1930*

BARIUM FLUOSILICATE

Treatment [1]	Quantity of residue					
	First cover, May 22		Second cover, June 4		Third cover, June 14	
	Mg per apple	*Mg per cm²*	*Mg per apple*	*Mg per cm²*	*Mg per apple*	*Mg per cm²*
Series B, test 1:						
Before spraying	----------	----------	----------	----------	0.258	0.011
After spraying	----------	----------	----------	----------	.502	.017

ARSENIOUS OXIDE

Series A, test 2:						
Before spraying	0.032	0.005	0.094	0.006	0.174	0.007
After spraying	.160	.016	.180	.012	.300	.010

BARIUM FLUOSILICATE

Treatment [1]	Quantity of residue						
	Fourth cover, June 26		Fifth cover, July 20		Sixth cover, Aug. 12		Residue at harvest, Oct. 15
	Mg per apple	*Mg per cm²*	*Mg per apple*	*Mg per cm²*	*Mg per apple*	*Mg per cm²*	*Mg per cm²*
Series B, test 1:							
Before spraying	0.794	0.021	1.270	0.022	2.120	0.025	----------
After spraying	1.156	.029	1.860	.029	----------	----------	0.019
Series A, test 1:							
Before spraying	----------	----------	1.655	.027	----------	----------	----------
After spraying	----------	----------	1.405	.022	1.900	.022	.017

ARSENIOUS OXIDE

Series A, test 2:							
Before spraying	0.210	0.005	0.425	0.007	0.750	0.008	----------
After spraying	.580	.013	.725	.011	1.100	.013	0.009

[1] For spray schedule, see table 14.

REMOVAL OF FLUORINE SPRAY RESIDUES

In 1930 some tests were made to determine the feasibility of removing residues of barium fluosilicate from the fruit by means of chemical solvents. Fruit that had had 2 applications of lead arsenate, followed by 5 applications of barium fluosilicate used at the rate of 4 pounds to 100 gallons of water with fish-oil or mineral-oil emulsion, was washed in a flood machine with 1 percent hydrochloric acid at temperatures of 75° to 110° F., and with 1 percent sodium carbonate at temperatures of 90° to 110°. Before it had been cleaned the fruit had an average deposit of 0.04 grain of fluorine per pound. Treatment with hydrochloric acid resulted in an average deposit of 0.009 grain of fluorine per pound when washed at 75° F., 0.006 grain per pound when washed at 90°, and 0.005 grain per pound when washed at 110°. Treatment with sodium carbonate at 90° and 110° resulted in an average deposit of 0.014 grain of fluorine per pound.

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In March 1933 three lots of fruit that had been sprayed the previous summer two or three times with sodium fluoaluminate (cryolite) at the rate of 3 pounds to 100 gallons of water with mineral-oil emulsion were washed with 1.5 percent hydrochloric acid, with 5 percent sodium silicate, and with 18 percent sodium carbonate,[3] respectively. Fruit that has been kept in storage for several months is more difficult to clean than when freshly harvested; therefore temperatures of 110° F. were used for the acid and sodium carbonate and 120° for the sodium silicate. This fruit had a maximum deposit of 0.022 grain of fluorine per pound before it had been washed. Treatment with hydrochloric acid resulted in an average deposit of 0.004 grain of fluorine per pound; with sodium silicate, of 0.007 grain per pound; and with sodium carbonate, of 0.015 grain per pound.

Since methods of analyses for fluorine have not yet been perfected, these results are only preliminary, but they indicate the quantity of fluorine residue that it may be possible to remove by suitable washing with a solution of hydrochloric acid, sodium silicate, or sodium carbonate.

SUMMARY

This bulletin records the results of experiments conducted under arid conditions at Yakima, Wash., to determine whether certain fluorine compounds could be used as substitutes for lead arsenate for the control of the codling moth.

The fluorine compounds studied are apparently not so toxic as lead arsenate on the basis of equal weight. This may be due in part to a lack of adhesiveness. Because of their cheapness, however, larger quantities may be used without increasing the cost. The lack of adhesiveness may be overcome by using fish-oil sticker or a mineral-oil emulsion with them.

Tests of barium fluosilicate, potassium fluosilicate, and sodium fluoaluminate (cryolite) at the rate of 3 or 4 pounds to 100 gallons of water, plus 1 pint of fish oil or ¾ gallon of emulsified mineral oil, reduced the wormy fruit in about the same percentage as lead arsenate did at the rate of 2 pounds to 100 gallons of water, without a sticker except in one experiment, and reduced the quantity of stung fruit by a greater percentage.

Except in some of the tests conducted in 1927, no fruit or foliage injury resulted from any of the experiments. In the limited number of analyses made to determine the residue on the fruit at the time of harvest, the residue from these materials was less than that left by lead arsenate and was as easily removed.

The fluorine compounds should not be used with lime-sulphur or with spreaders containing lime.

[3] These tests were made by A. L. Ryall, assistant pomologist, Bureau of Plant Industry, and the analyses were made by the junior author.

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LITERATURE CITED

(1) Abbott, W. S., Culver, J. J., and Morgan, W. J.
1926. EFFECTIVENESS AGAINST THE SAN JOSE SCALE OF THE DRY SUBSTITUTES FOR LIQUID LIME-SULPHUR. U.S. Dept. Agr. Bul. 1371, 27 p.

(2) Carter, R. H.
1928. SOLUBILITIES OF SOME INORGANIC FLUORIDES IN WATER AT 25° C. Indus. and Engin. Chem. 20: 1195.

(3) ———
1929. COMPATIBILITIES OF INSECTICIDES. I. FLUOSILICATES AND CRYOLITE WITH ARSENATES. Jour. Econ. Ent. 22: 814–818.

(4) ———
1930. SOLUBILITIES OF FLUOSILICATES IN WATER. Indus. and Engin. Chem. 22: 886–887.

(5) ———
1930. FLUOALUMINATES OF THE ALKALI METALS. Indus. and Eng. Chem. 22: 888–889.

(6) ———
1931. DETERMINATION OF BARIUM FLUOSILICATE SPRAY RESIDUE. Indus. and Engin. Chem., Anal. Ed. 3: 146–147.

(7) ———
1931. THE INCOMPATIBILITY OF LIME WITH FLUOSILICATES. Jour. Econ. Ent. 24: 263–268, illus.

(8) Hood, C. E.
1929. FISH OIL AS AN ADHESIVE IN LEAD-ARSENATE SPRAYS. U.S. Dept. Agr. Tech. Bul. 111, 28 p., illus.

(9) Marcovitch, S.
1928. STUDIES ON TOXICITY OF FLUORINE COMPOUNDS. Tenn. Agr. Expt. Sta. Bul. 139, 48 p., illus.

(10) ——— and Stanley, W. W.
1929. CRYOLITE AND BARIUM FLUOSILICATE: THEIR USE AS INSECTICIDES. Tenn. Agr. Expt. Sta. Bul. 140, 19 p., illus.

(11) Newcomer, E. J.
1926. LABORATORY EXPERIMENTS WITH ARSENICALS IN THE CONTROL OF THE CODLING MOTH. Jour. Agr. Research 33: 317–330.

(12) Porter, B. A., and Sazama, R. F.
1928. A NEW METHOD OF USING FISH-OIL AS AN ADHESIVE. (Scientific note.) Jour. Econ. Ent. 21: 633–634.

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TECHNICAL BULLETIN No. 374 JULY 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

EFFECTIVENESS OF THE SWINE SANITATION SYSTEM IN THE SOUTH

By E. M. NIGHBERT, *associate veterinarian*, and J. W. CONNELLY, *senior lay inspector, Zoological Division, Bureau of Animal Industry*

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PURPOSE OF INVESTIGATION

In the control of internal parasites, the system of swine sanitation developed in McLean County, Ill.,[1] has come into common use in the Middle West and has attracted the attention of swine growers in other regions. Through this system many farmers have prevented much of the heavy loss due to the ascarid, or common intestinal roundworm, *Ascaris suum*. Some producers have raised about 50 percent more pigs with the same number of sows than they had raised under the usual hog-lot conditions. In the Corn Belt, farmers have also been able to get pigs ready for market from 4 to 8 weeks earlier with a saving of both feed and labor, and the pigs in each litter have been of uniform size. Litters raised under the sanitary system contain practically no runts.

This method seemed to be applicable to other regions. In order to test the swine sanitation system under farm conditions in the South, the Bureau of Animal Industry accepted, from among numerous offers of cooperation, the opportunity to conduct a series of trials in Colquitt County, Ga. This county, in southwestern Georgia, was favorably situated in regard to marketing and slaughtering facilities. The additional fact that the bureau was conducting meat inspection at an establishment in Moultrie afforded an opportunity for post-mortem examination of pigs involved in this investigation. Many of the farmers in the county were interested in reducing the losses that had caused discouragement in raising pigs for market. The prospect of cooperation from farmers, as well as the other favorable circum-

[1] RAFFENSPERGER, H. B., and CONNELLY, J. W. THE SWINE SANITATION SYSTEM AS DEVELOPED BY THE BUREAU OF ANIMAL INDUSTRY IN MCLEAN COUNTY, ILL. U.S. Dept. Agr. Tech. Bul. 44, 20 p. 1927.

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stances, led to the establishment of a temporary field station in Moultrie for the study of this problem.

At the outset of the experiment, which began in 1926 and continued through 1930, it was realized that between the Middle West and the South there were material differences in climate, types of soil, parasite infestation, and other conditions affecting the production of hogs.

The sanitary system of handling sows and their litters is primarily a control measure for preventing injury to young pigs by the swine ascarid and is based on the life cycle of this parasite. However, this experiment with the sanitation system was carried further to include a consideration of the effectiveness of the system against kidney worms, nodular worms, thornhead worms, lungworms, hookworms, and whipworms.

PRELIMINARY OBSERVATIONS

SOIL AND CLIMATE OF COLQUITT COUNTY, GA.

Colquitt County, Ga., is located in the higher portion of the Coastal Plain area of the State. The soil is of the gray and yellow sandy loam type. The land is undulating and fairly well drained. The upland is usually tilled, but the low, well-shaded, moist land is used for permanent pasture.

According to reports of the United States Weather Bureau, which maintains a station at Thomasville, nearby, the average date of the last killing frost in this vicinity in the spring is March 14, and the average date of the first killing frost in the fall is November 15. There is, therefore, a growing season of 246 days. The district is well below the snow line; the annual, normal rainfall is about 52 inches, and the annual mean temperature is about 67° F.

It is generally recognized that conditions such as are found in this part of Georgia—particularly warmth and abundant moisture—are favorable to the development of most parasites in swine and other farm animals. However, these conditions are offset to a considerable degree, as regards the ascarid of swine, by the fact that pastures are larger and less densely stocked than those in the Middle West. It is well known that with light stocking there tend to be fewer parasites.

CUSTOMARY METHOD OF RAISING PIGS

The customary practice of raising pigs in southern Georgia involves the use of native pasture, commonly a piece of low, moist ground. A fenced lane usually connects the pasture, which may or may not be fenced, with an enclosure convenient enough to the farmhouse to allow feeding during the winter and other seasons when there is a shortage of pasturage. Small enclosures and lanes of this type used by hogs year after year tend to become heavily infested (fig. 1).

Swine growers in the South, as a rule, do not provide hog houses but sometimes use improvised shelters set up in fields or against sheds or barns (fig. 2). Shortly before farrowing, sows are placed in pastures where they will get some protection and shelter from timber or undergrowth while farrowing their pigs. When the pigs are several weeks old they are allowed to run in the pasture with the sows and other hogs, and so become exposed to worm infestation. Under such conditions pigs suckle the sows for long periods. Although the practices described are commonly followed in Colquitt County, much of which is free range, some hog producers keep their stock in fenced pastures

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in order that herd improvement may be carried on more conveniently. It is a common practice to raise both spring and fall litters.

FIGURE 1.—Feeding hogs in a lane leading to low-lying wet pasture. This practice, common in the South, tends toward heavy infestation with worm parasites.

The main crops used for finishing hogs in southern Georgia are corn, peanuts, and sweetpotatoes, which are fed by allowing the hogs to harvest the crops in the fall and winter. In some cases these feeds

FIGURE 2.—A typical herd resulting from indiscriminate breeding and little attention to sanitation. Note the improvised farrowing shelter in the background.

are supplemented with a concentrate such as tankage. The practice commonly brings the hogs to market finish during the fall and winter months, and it also leaves a long period of light feeding for pigs farrowed in the spring.

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The grazing crops used for pigs are permanent native pastures, winter oats, and rye. The temporary crops are sown early in the fall and pastured in late fall, winter, and spring.

The feeding methods necessarily influence the age at which hogs are slaughtered. In order to determine the approximate age of hogs when sold for market, the writers examined the incisor teeth of 8,308 hogs as they were slaughtered at one of the local slaughtering establishments. The ages of these hogs ranged from 12 to 18 months, the average being about 14 months.

FARM SURVEY

Before the experimental work was begun the writers conducted a survey of all farms offering to cooperate in the work. Through the cooperation of the county extension agent and the local chamber of commerce a series of farm visits was conducted in order to make a careful study of worm infestation of herds, customary losses from such infestations, and the cause of runty conditions in young pigs. The general management of hogs on farms, particularly of sows and their litters, was also noted during the survey. Moreover, before undertaking the actual work of the project, it was necessary to consider the kind of crops that could be grown.

Most of the farmers believed that worm infestation was the principal obstacle to the swine industry in this area. Practically all herds inspected showed evidence of worm infestation, either in runty pigs or poorly developed animals. On the other hand, there were few filth-borne diseases such as bull nose, sore mouth, scours, and mange. The absence of these conditions was due largely to the fact that, in general, pigs in this county have relatively large fields or pastures in which to forage. Filthy hog lots and mud wallows were exceptions to the general rule partly because the sandy loam soil drains readily after rains. This factor may have had a bearing on the results of the project.

During the course of the survey the writers interviewed 28 farmers who were considered to be successful hog raisers. Of these, 21, or three fourths of the number, said that hog raising was profitable, whereas the remaining 7 believed it did not pay. On the basis of these statements it is probable that growing hogs in this locality is usually profitable in greater or less degree.

The survey also showed the presence of rickets and associated deficiency ailments that could be corrected by feeding a properly balanced ration and some simple mineral mixture.

One of the details of the survey was the collection of fresh drop pings from pigs. These were taken both as composite samples and as specimens from individual animals and examined microscopically for worm eggs. All specimens collected in the survey showed indications of ascarids and other kinds of worms. Furthermore, subsequent post-mortem examinations, which were made at every opportunity, either in the field or laboratory, usually showed the presence of ascarids and other intestinal worms. In some cases there were sufficient numbers of worm parasites to cause serious injury to the host animals. Ascarids, nodular worms, lungworms, stomach worms, and kidney worms were found in every herd from which pigs were examined, and there was sufficient evidence to indicate that these parasites were causing injury and interfering with the growth and development of the animals. This evidence of worm infestation justified

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the statements of the farmers that this was a drawback to hog raising in Colquitt County.

EXPERIMENTAL PROCEDURE

MODIFIED SYSTEM OF SWINE SANITATION USED

After a consideration of all the factors involved in the production of swine under local conditions, a modified system of swine sanitation was presented to the farmers who orally agreed to the following procedure:

(1) That they would provide suitable temporary grazing crops for sows and pigs, both for spring and fall litters.

(2) That such grazing crops would be planted in fields that had been plowed and not used by hogs during the previous year, these fields to be as far away as possible from premises long used by hogs.

(3) That the sows would be placed in the clean fields 3 or 4 days before farrowing, and that shelter—preferably a portable farrowing house—and watering facilities would be provided.

(4) That the pigs would be kept in the original clean field or some other clean field until they were at least 4 months old, the sows to be removed when the pigs were from 60 to 70 days old.

(5) That a reliable record would be kept of the date and number of pigs farrowed, including the number of losses and the cause of losses, if obtainable.

In addition, the writers urged growers to use the most practical methods of improving and handling hogs. Purebred boars of good type were recommended for all farms where financial conditions permitted their use. It was further urged that the breeding herds be given good attention and sufficient feed of the proper kind to insure litters of strong pigs.

The swine owners were urged to breed their sows according to a schedule in order that the litters might be farrowed on the same dates as far as possible, thus utilizing the clean fields for the litters to the best advantage because of the more uniform age of the pigs.

As the sandy soil of the Coastal Plain is of a type that does not easily adhere to the sows, washing the animals before placing them in clean fields was usually unnecessary. Washing was necessary only in a few cases when sows had had access to muddy soil. The use of a crate on runners or other conveyance, for transferring each sow and her litter to a clean field, was also omitted in this modified system as there was no indication of any sow's carrying worm infection of any consequence on her udder, feet, or other part of the body.

The basic modifications of the original swine sanitation system consisted in farrowing both spring and fall litters on pasture in temporary shelters, instead of farrowing the spring litters in a permanent farrowing house. Thus the growers omitted most of the procedure associated with the use of permanent farrowing houses in the McLean County system. The modifications are based, for the most part, on the principles outlined by Ransom [2] for fall farrowing in the Corn Belt in connection with swine sanitation.

In carrying out the details of the swine sanitation system, 32 farmers cooperated to some degree in the experimental study on their farms. A number of others began the work but failed to continue

[2] RANSOM, B. H. THE PREVENTION OF ROUNDWORMS IN PIGS. U.S. Dept. Agr. Leaflet 5, 8 p., illus. 1927.

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until the pigs were raised, and they were therefore dropped from the experiment.

The writers kept in close touch with these farms by visiting the premises frequently and recorded data on number of pigs farrowed, losses at farrowing time and on pasture, and the number of pigs marketed, kept, or sold for breeding. The writers also made post-mortem examinations at time of slaughter, as all pigs were marketed at one packing plant, where cordial cooperation was given by the packing company.

In addition to the 32 farmers just mentioned, 8 others agreed to allow their herds to be studied as controls. These farmers were to use their customary method of raising, feeding, and marketing hogs without giving any attention to the sanitation system. The owners of these control herds were classed as better than average hog producers in this locality, a fact which had a bearing on the results of the investigation. Visits were made also to these farms at frequent intervals in order to obtain information similar to that obtained for the pigs raised under the sanitation system.

GRAZING CROPS USED IN EXPERIMENTS

The possibility of having continuous grazing crops available for the sows and growing pigs was favorable to the successful operation of the modified system of swine sanitation. The climate of Colquitt County is such that crops may be sown for both summer and winter grazing. The crops used for summer grazing were field peas, sorghum, velvetbeans, and millet, whereas the principal crops used for pasture in the fall and winter were oats, rye, and Austrian winter peas. The oat crop was especially well suited for grazing, the sows being allowed to farrow in a field of growing oats, where the pigs in some instances remained until the mature crop was "hogged off." By this method the pigs were kept on clean ground away from premises contaminated with worm eggs and larvae until ready for finishing on early corn. In case no grazing crop was available for a sow and her litter, a field that had been cropped during the year was utilized, provided, of course, that no other hogs had grazed the field since the ground was plowed.

The pigs on pasture had access to a mixture of ground limestone and common salt, equal parts by bulk, with enough tankage added to provide flavor. This mixture was kept before most of the sows and pigs at all times as an aid in stimulating rapid, normal development.

EQUIPMENT FOR SOWS AND THEIR LITTERS

Permanent farrowing pens and houses are not in general use in the South and, therefore, are not considered in the sanitation method as modified for this region. An individual, portable farrowing house (figs. 3 and 4), designed by the investigators to meet conditions of the district, was used to some extent in protecting litters during chilly nights and cold rains. This type of farrowing house can be constructed at small cost.

RESULTS OF EXPERIMENTS AND DISCUSSION

PIGS RAISED AND MARKETED

As to the degree of cooperation in carrying out the swine sanitation system on their farms, the cooperators were classified as being in three groups: "Excellent", "good", and "fair." By "excellent" is meant

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those who carried out all the essential details of the swine sanitation system and applied the methods as completely as possible under farm conditions. By "good" is meant those who were interested in swine sanitation and for a time observed the more important details but

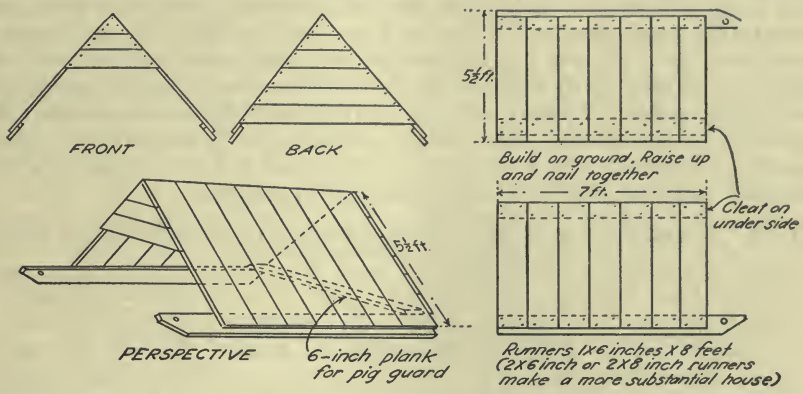

FIGURE 3.—Individual, portable farrowing house suitable for the Coastal Plain area of the Southern States.

later carried them out only partly. By "fair" is meant those who showed interest at the outset but neglected many of the details of the work during the time the pigs were being raised. One of the cooperators was classed as "excellent", 6 as "good", and 25 as "fair." The

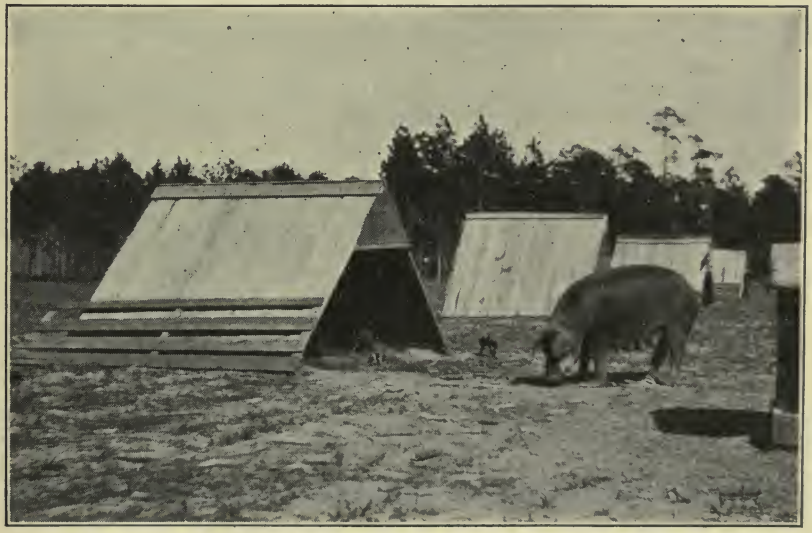

FIGURE 4.—Group of portable farrowing houses used on the premises of a cooperator.

predominance of "fair" cooperators and the fact that owners of control pigs were farmers of more than average ability largely accounts for some of the cases in which the sanitation pigs had more parasites than the others. It was obviously impossible to foresee the character of cooperation.

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Tables 1 to 4 show the principal results obtained by the cooperators during the 5-year period. Since it was not practicable for the writers to make an actual count of the pigs at time of farrowing, it was necessary to accept the owners' figures. However, the systematic and regular visits to each farm showed that the count was so nearly correct that any error in the figures given had but slight, if any, bearing on the results. It was impracticable also, under the conditions of the work, to obtain birth weights of the pigs for use in computations of individual gains. However, in proportion to total gains—commonly exceeding 150 pounds—the fairly uniform birth weight of pigs—usually between 2 and 3 pounds—is too small a factor to have a significant effect on results of the kind here presented.

TABLE 1.—*Results of raising pigs under the system of swine sanitation and without attention to sanitation, 1926–30*

Year and class of pigs	Farms in experiment	Brood sows	Pigs farrowed	Pigs to pasture	Pigs lost at farrowing time		Pigs lost on pasture— From disease	Pigs lost on pasture— From accident	Pigs lost on pasture— Total	
1926	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*
Sanitation pigs	9	46	330	252	78	23.6	3	7	10	4.0
Control pigs	3	16	97	88	9	9.3	27	6	33	37.5
1927										
Sanitation pigs	20	303	2,297	1,929	368	16.0	112	111	223	11.6
Control pigs	5	65	383	351	32	8.3	104	17	121	34.5
1928										
Sanitation pigs	20	181	1,329	1,084	245	18.4	104	58	162	14.9
Control pigs	6	40	281	251	30	10.7	73	13	86	34.3
1929										
Sanitation pigs	19	164	1,392	1,175	217	15.6	40	48	88	7.5
Control pigs	6	56	433	358	75	17.3	9	9	18	5.0
1930										
Sanitation pigs	15	78	700	566	134	19.1	14	14	28	4.9
Control pigs	5	20	170	136	34	20.0	0	0	0	0
Total or average:										
Sanitation pigs	-------	772	6,048	5,006	1,042	17.2	273	238	511	10.2
Control pigs	-------	197	1,364	1,184	180	13.2	213	45	258	21.8

Year and class of pigs	Pigs held on farms or sold for breeding	Pigs marketed	Average weight of pigs when marketed	Average daily gain of pigs (birth to market)	Pigs to pasture, saved or marketed	
1926	*Number*	*Number*	*Pounds*	*Pound*	*Number*	*Percent*
Sanitation pigs	45	197	190	0.70	242	96.0
Control pigs	14	41	187	.56	55	62.5
1927						
Sanitation pigs	246	1,460	166	.61	1,706	88.4
Control pigs	0	230	187	.59	230	65.5
1928						
Sanitation pigs	75	847	151.5	.55	922	85.1
Control pigs	0	165	186	.54	165	65.7
1929						
Sanitation pigs	187	900	151.5	.76	1,087	92.5
Control pigs	165	175	171	.58	340	95.0
1930						
Sanitation pigs	538	0	----------	----------	538	95.1
Control pigs	136	0	----------	----------	136	100.0
Total or average:						
Sanitation pigs	1,091	3,404	159.9	.63	4,495	89.8
Control pigs	315	611	182.1	.57	926	78.2

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The data in table 1 include results, such as losses at farrowing time and losses from accident on pasture, that obviously do not concern the swine sanitation system. The data for the various years also show considerable irregularity resulting from many variable local factors. The entire absence of losses among the control pigs on pasture in 1930 is especially noteworthy; as hog men are well aware, this is an unusual record in which the element of chance happened to be highly favorable. However, the 5-year record of "pigs to pasture" that were saved or marketed showed that the swine sanitation system gave an 89.8 percent result as compared with 78.2 percent for the controls.

A study of the causes of loss showed that in most cases deaths at farrowing time were from overlying, exposure, drowning, and similar causes. Losses from accident were the result of injuries by other hogs or the effects of a wide range of miscellaneous causes. Losses from disease were due to hog cholera, pneumonia, malnutrition, poisioning by plants, and similar causes. Cholera, of course, may be prevented by immunizing the pigs while young. Pneumonia was not observed in pigs less than 4 weeks old, but there were cases of pigs ranging from 4 to 6 months of age, especially in dry seasons, when there was considerable dust in the hog lots. This disease was most common among underfed herds, in which the pigs were probably more susceptible to bacterial infection. Losses from poisoning may be lowered by keeping the pigs away from fields where young cocklebur and other poisonous plants are growing. Losses from diseases were noticeably greater in herds kept by farmers who were lax in their methods of management.

In order to make a comparison of the market weights of the pigs from the two groups, the writers kept records of the weights and ages of all pigs marketed during the first 4 years of the experiment. None had been marketed in 1930 by the time the experiment closed (table 2).

TABLE 2.—*Comparison of market weights and ages of sanitation and control pigs, 1926–29*

Year	Sanitation pigs				Control pigs			
	Pigs slaughtered	Average weight	Average age	Average daily gain	Pigs slaughtered	Average weight	Average age	Average daily gain
	Number	*Pounds*	*Days*	*Pound*	*Number*	*Pounds*	*Days*	*Pound*
1926	197	190	270	0.70	41	187	335	0.56
1927	1,460	166	272	.61	230	187	318	.59
1928	847	151.5	276	.55	165	186	347	.54
1929	900	151.5	200	.76	175	171	296	.58
Total or average	3,404	159.9	251	.63	611	182	321	.57

Since the control pigs, by reason of their slower growth, were more than 2 months older when marketed, the final weights are not comparable as a basis of judging the effectiveness of the system. The average daily gains, however, provide comparable figures which for each year were higher for the sanitation pigs.

The value of the sanitation system is judged primarily in terms of thrift, as indicated by gains in weight per day and number of sanita-

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tion pigs raised and marketed as compared with similar data for the controls. Figures 5, 6, and 7 show typical lots of pigs in both the sanitation and control groups.

FIGURE 5.—A control lot of pigs, ranging in age from 10 weeks to 7 months.

FIGURE 6.—A lot of sanitation pigs ranging in age from 10 weeks to 4 months.

POST-MORTEM OBSERVATIONS

Further data bearing on the infestations of the experimental pigs were provided by post-mortem observations for the first 4 years during which pigs were marketed. As previously stated, the post-mortem examinations were made at a local packing plant.

In the conduct of these examinations the viscera of at least one fourth of each group of pigs slaughtered each year were examined in order to determine the number and percentages of viscera infested

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with ascarids and other internal parasites and also to obtain data on the number of the different parasites present so far as they could be counted.

In addition to examining the viscera of 592 pigs (table 3), the writers inspected the carcasses of the same animals and 1,600 others. Careful observation was also made of the livers of all the pigs, since previous reports indicated that the livers of a large proportion of pigs slaughtered in the South were parasitized by kidney worms. It is impracticable to count kidney worms, but table 4 shows the

FIGURE 7.—Sanitation pigs marketed when 6 months old, averaging 200 pounds.

general results of post-mortem examination of carcasses and livers for the presence of these parasites.

TABLE 3.—*Results of examinations of viscera of sanitation and control pigs, 1926–1929*

Year and class	Examinations	Viscera infested with parasites [1]		Parasites, per pig, found in viscera [2]				
				Ascarids	Hookworms	Nodular worms	Thornhead worms	Whipworms
1926	*Number*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Number*	*Number*
Sanitation pigs	52	45	86.5	5.40	0.04	4.53	0.19	1.02
Control pigs	11	5	45.5	3.36	0	41.09	3.90	0
1927								
Sanitation pigs	241	183	75.9	4.64	0	3.15	.71	.02
Control pigs	53	47	88.7	1.74	.04	4.55	9.23	0
1928								
Sanitation pigs	68	49	72.1	4.98	1.56	10.12	.38	0
Control pigs	16	15	93.8	4.13	0	0	3.44	.38
1929								
Sanitation pigs	120	90	75.0	5.59	.99	0	.09	.64
Control pigs	31	25	80.6	5.09	.06	0	.52	0
Total or average:								
Sanitation pigs	481	367	76.3	5.01	.65	5.93	.34	.42
Control pigs	111	92	82.9	3.17	.03	15.21	4.27	.10

[1] For data on kidney-worm infestation of carcasses and livers, see table 4.

[2] It was not practicable, under field conditions, to count lungworms, but for the pigs examined during the 4 years observations on the effects of this parasite were as follows: Sanitation pigs, 60 free, 421 slight to extensive infestation; control pigs, 0 free, 111 slight to extensive infestation. "Slight" signifies 1 area of infestation in lung; "extensive" signifies several areas of infestation in lung.

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TABLE 4.—*Results of post-mortem examinations for kidney-worm infestation of carcasses and livers of sanitation and control pigs, 1926–29*

Year and class of pigs	Carcasses examined	Carcasses parasitized		Livers parasitized	
	Number	*Number*	*Percent*	*Number*	*Percent*
1926					
Sanitation pigs	150	9	6.0	76	50.7
Control pigs	44	15	34.1	[1] 35	79.5
1927					
Sanitation pigs	892	308	34.5	670	75.1
Control pigs	183	67	36.6	168	91.8
1928					
Sanitation pigs	264	120	45.5	246	93.2
Control pigs	110	84	76.4	110	100.0
1929					
Sanitation pigs	441	118	26.8	322	73.0
Control pigs	[2] 108	55	50.9	103	95.4
Total or average:					
Sanitation pigs	1,747	555	31.8	1,314	75.2
Control pigs	445	221	49.7	416	93.5

NOTE.—Percentages are based on total number examined.

[1] Identity of 4 livers lost.
[2] Identity of 7 carcasses lost.

By "livers parasitized" is meant either that kidney worms were present in the livers or that the organs had been infested with the parasite leaving scars or abscesses which caused the condemnation of the livers for use as food. By "carcasses parasitized" is meant that kidney worms were present in the kidneys, kidney fat, and frequently in the loin meat, causing these otherwise edible products to be unsuitable for use as food. As inspected, the hog carcasses contained the kidneys and attached fat.

The number of parasites in both classes of pigs at the time of slaughter was, in general, small. The most significant figures in tables 3 and 4 are the relative percentages of parasitized viscera, livers, and carcasses for the 4-year period. The percentages for the sanitation lots are materially smaller than for the control lots. These data are of interest in connection with previous figures on gains per pig. Both sets of data show the superior condition of the sanitation pigs. Evidently the small numbers of intestinal parasites present did little damage through mechanical obstruction. The injury probably consisted in some disturbance of digestive and body functions through invasion of tissues. In these invasions even small numbers of parasites seemed to have a retarding effect on growth and development.

RESULTS OF SYSTEM AS USED BY THE "EXCELLENT" COOPERATOR

The results obtained by the one cooperator classed as "excellent are of interest, also, in showing the effectiveness of the system when all details were closely carried out. On the farm of this cooperator 58 sows farrowed during the 5 years, turned to pasture 420 pigs, an average of 7.2 pigs per litter. The losses on pasture from accident and disease were 30, or 7.1 percent. The losses from disease alone were 18, or 4.3 percent. Hence on this farm the system was 95.7 percent effective in protecting against loss by death from disease on pasture.

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This cooperator marketed his pigs at an average age of 183 days and an average live weight of 185.7 pounds. This was a saving of 68 days as compared with the average for all the sanitation pigs (table 2), and a saving of 138 days as compared with the average for the control pigs. Furthermore, the pigs raised by this cooperator weighed 3.7 pounds per head more than the control pigs, in spite of the fact that the latter were about 4½ months older. The post-mortem examination of the excellent cooperator's herd revealed only 7 percent of parasitized carcasses.

CONCLUSIONS AND SUMMARY

The experimental study of swine sanitation on 40 farms in Colquitt County, Ga., during the period 1926–30 indicates that this system as modified for southern conditions is effective in reducing materially the customary losses in growing pigs. The modification consists in having the sows farrow on pasture rather than in permanent farrowing houses; also, the sows need not be washed before farrowing in sections where the soil is sandy and well drained.

Though originally designed to control ascarids of young pigs, the system is also moderately effective against other worm parasites including kidney worms, which infest livers, kidneys, and loin tissues. The infestations are the cause of considerable loss as a result of condemnations, by inspectors, when the hogs are slaughtered.

Pigs raised under the sanitation system make more rapid daily gains than pigs raised with no attention to sanitation.

The sanitation system of raising pigs enables the farmer to raise more and better pigs from the same number of sows.

The value of the system is greatest when the hog grower follows every detail.

A study of the records of all classes of cooperators using the swine sanitation system showed that on their farms there occurred a total of 772 farrowings, resulting in 5,006 pigs going to pasture, an average of 6.5 pigs per litter. Barring deaths from accident on pasture, only 273 pigs, or 5.5 percent, were lost, indicating that the system was 94.5 percent effective in protecting against losses of the kind the system was designed to prevent.

On the farms of control-herd owners 197 farrowings occurred during the 4 years, resulting in 1,184 pigs turned to pasture, or an average of 6 pigs per litter. The losses on pasture from disease were 213, or 18 percent. Hence, on farms on which no attention was given to sanitation in raising pigs, only 82 percent of the pigs that were turned to pasture and that escaped accident were raised for market or kept for breeding.

When losses from accident were included, the percentage of pigs saved or marketed, based on the number placed on pasture, was 90.0 percent for the sanitation pigs and 78.2 percent for the controls.

The average daily gains of the experimental pigs were 0.63 pound for the sanitation lots and 0.57 pound for the controls.

Post-mortem examination of the sanitation pigs slaughtered during the experiment showed that 75.2 percent of the livers were parasitized, whereas of the livers of control pigs 93.5 percent were parasitized.

Kidney-worm infestation of the sanitation-pig carcasses was 31.8 percent, as compared with 49.7 percent in the controls. Examina-

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tion of the viscera from the sanitary pigs showed 76.3 percent ascarid infestation, whereas in the control pigs there was 82.9 percent infestation.

The numbers of different parasitic worms present in the experimental lots, each year, as indicated by post-mortem examination, varied considerably. However, the number was small as compared with typical infestations of pigs kept in old hog lots.

The effectiveness of the system when followed in detail is illustrated by the results obtained by the "excellent" cooperator. During the 5 years his losses of pigs from disease alone were only 4.3 percent, as compared with 5.5 percent for all sanitation lots and 18 percent for the controls.

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Technical Bulletin No. 375 August 1933

SELECTIVE LOGGING IN THE SHORTLEAF AND LOBLOLLY PINE FORESTS OF THE GULF STATES REGION

BY

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TECHNICAL BULLETIN No. 375 AUGUST 1933

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

SELECTIVE LOGGING IN THE SHORTLEAF AND LOBLOLLY PINE FORESTS OF THE GULF STATES REGION

By R. D. GARVER,[1] *senior forester*, and R. H. MILLER, *associate engineer, Forest Products Laboratory,*[2] *Branch of Research, Forest Service*

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INTRODUCTION[3]

Selective logging is one of the surest methods of keeping most southern yellow pine lands productive and of keeping small, unprofitable trees out of the mills. It is a simple and practical step in the development of permanent or sustained-yield operations, and therefore merits the consideration of all timberland owners of the southern pine region.

Selective logging or selective cutting correlates present-day silvicultural and the economic requirements in a practical way. Such handling of forest lands may involve not only the selection of the trees to be felled but also the determination of the order in which different areas shall be logged and, sometimes, in addition the determination of the species to be cut. For stands of southern yellow

[1] Acknowledgment is made to C. V. Sweet of the Forest Products Laboratory for suggestions in planning the work and preparing the report, to A. C. Wollin, also of the laboratory, for assistance in collecting and computing the data, to E. L. Demmon of the Southern Forest Experiment Station for helpful suggestions in planning the field work and preparing the report, and to R. A. Chapman of the station for assistance in collecting the field data. Thanks are also due to D. C. Gates, Fordyce Lumber Co., Fordyce, Ark., to L. D. Gilbert, Southern Pine Lumber Co., Diboll, Tex., to T. W. Rosborough, Caddo River Lumber Co., Glenwood, Ark., and to Henry E. Hardtner, Urania Lumber Co., Urania, La., for their generous cooperation and assistance in the conduct of the investigation. The Southern Pine Association, through its officers and an advisory committee, rendered assistance in planning and carrying out the work.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] By E. L. Demmon, director, Southern Forest Experiment Station.

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pine, however, the method will involve mostly the selection of the trees to be felled. In general it provides for the removal of the larger and older trees and the defective smaller ones, and the reservation of the thrifty small and medium-sized trees for seed production and future growth. In designating the trees to be cut, minimum diameter limits should be used merely as a guide; the primary objective from a silvicultural standpoint, should be to leave only healthy, thrifty trees. Cutting practices on private land, however, must be governed somewhat by immediate economic considerations, and the owner, to operate successfully, may have to strike a balance in his cutting plan between silvicultural desirability and economic feasibility.

Southern yellow pine grows fast on good land, and timber growing on such areas appears to offer every promise of profit. Selective cutting is recommended as a sound method of handling most shortleaf and loblolly pine lands. The information in this bulletin should be helpful to owners of southern pine forest land in setting up management plans that will result in sustained-yield operations, which in turn create stable land ownership and contribute to the industrial and social welfare of the region.

THE FORESTRY SITUATION IN THE SHORTLEAF AND LOBLOLLY PINE STANDS OF THE GULF STATES REGION

The existing forestry situation in the Gulf States is unique in that the region includes some areas presenting some of the best examples of timber growing and other areas that are completely stripped of forest growth. Although there are notable instances of good forestry practice in the region, they are few in number; in fact it is estimated that less than 7 percent of the region as a whole is under the simplest kind of forest management, such as intentionally leaving an occasional seed tree. Furthermore, not more than 1 percent of the existing stands are fully stocked with tree growth (*3*, *4*).[4] Until very recently, competing timber regions and even local industries thought that the South would cut out all its timber during the early part of the twentieth century, but within the last decade it has become increasingly evident that because of the strong, natural regenerative capacity of the southern yellow pines the region is not going to cut out for a long time, if at all, and that with fire protection and good forest management it will produce an enormous amount of wood for all time. The chances that forestry practice will be successful on shortleaf and loblolly pine areas are excellent; second-growth timber, which grew to merchantable size not because of fire protection and management but in many instances without either, now makes up nearly three fourths of the present cut, and the proportion is increasing yearly as the supply of virgin timber becomes exhausted.

The Gulf States region, as considered in this bulletin, is made up of Louisiana, Texas, Oklahoma, Arkansas, Mississippi, and Alabama; it contains about 46,800,000 acres of shortleaf-loblolly pine timberland (fig. 1). Of this area, about 2,700,000 acres are covered with virgin saw timber, 16,400,000 with second-growth saw timber, and 11,500,000 with cordwood, while 14,400,000 acres are restocking and 1,800,000 acres are deforested.

[4] Italic numbers in parentheses refer to Literature Cited, p. 53.

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PURPOSE OF THE INVESTIGATION

The primary purpose of this bulletin is to present the results of selective cutting and clear cutting on typical lumber operations in shortleaf-loblolly pine areas of the Gulf States region. To get these results it was necessary to determine: (1) The costs both of logging and of milling trees of different diameters; (2) the quantity, grade, and sales value of the lumber produced from them; and (3) the gross return when different volumes of timber were removed from the stand, under selective cutting, for lumber. It has been recognized for some time that such information is needed by the lumberman who wants to

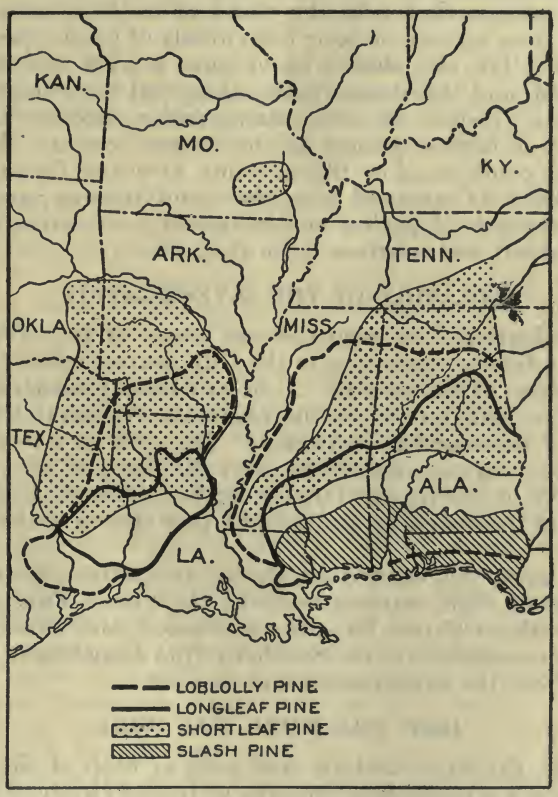

FIGURE 1.—Commercial range of the southern yellow pines in the Gulf States region.

cut out and move on, as well as by the forest-land owner who desires to handle his holdings so as to produce successive crops of timber. The information in this bulletin is intended to serve two main purposes: (1) To present, for actual going operations in southern yellow pine, the financial returns under clear cutting and under selective cutting; and (2) to provide basic data for the use of timberland owners who wish to work out selective cutting limits for their own timber.

SELECTIVE LOGGING

Selective logging, as the term is used in this bulletin, may be defined as a partial-cutting practice that, through judicious selection of the

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trees to be removed, meets both silvicultural and economic requirements in such a way as to perpetuate and improve the forest and at the same time to maintain or actually increase the profits to the owner (*9*). In practical application the areas to be logged should be chosen as carefully as the individual trees, so that selective logging on a going operation calls for the proper selection of both the trees to be cut and the areas to be logged. The selection of logging areas is extremely important, particularly when selective cutting is first started on a large tract. The oldest timber, other things being equal, should be cut first.

Selective cutting, as the term is used here, does not mean a "cream-skimming" process that robs the stand of its best trees and leaves nothing but poor species or poor individuals of goods species to form the next cut. The aim should be to leave a good and thrifty stand on the ground, and this necessitates taking out poor trees along with the good ones. Hence, the first cutting under selective logging often fails to yield as high a quality as the owners expect. The practice should not be condemned on this account, however, for the poor trees must eventually be removed from the stand anyway, and with such cutting the rewards of quality and increased increment come as early as the second cut and continue from that time.

LOCATION OF THE INVESTIGATION

The investigation here reported was made at four typical, large, band-mill lumbering operations in the Gulf States region. Study no. 1 was in southern Arkansas; no. 2, in northern Louisiana; no. 3, in eastern Texas; and no. 4, on the Ouachita National Forest in the mountains of west-central Arkansas. The mills and the methods of logging at the various operations were similar and in general were representative of the region, but the timber differed, though all of it was typical of the shortleaf and loblolly pine stands of the Gulf States region.

The field work was carried on, during the latter part of 1929 and the first part of 1930, cooperatively by the Forest Products Laboratory, the Southern Forest Experiment Station, and four lumber companies that are members of the Southern Pine Association; an advisory committee from the same association assisted.

HOW THE WORK WAS DONE

In general, the same technic was used at each of the operations.

At each place a representative area of timber, from 13 to 54 acres, was chosen for study. In 2 operations clear cutting was followed and at the other 2, selective cutting. The timber from these areas was studied by a crew as it passed through all the different steps of lumber manufacture. These men went into the woods and the mills and determined the output per unit of time and the cost of lumber per thousand board feet for logs and trees of different sizes; in addition they graded and tallied the lumber from each log separately and determined the loss in volume and the change in quality caused by kiln drying and remanufacture. The same timber was studied both in the woods and in the mill. The trees and the logs were numbered in the woods so that the logs from each tree could be identified at any time during the work. Such a plan permits translating the results into terms of the forest at any stage of lumbering and at any

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time, and log by log if desirable. The quantity of lumber by grades and the value for trees of different diameters, for example, were obtained directly by adding the figures on the lumber that came from the logs cut from each tree. Time and output records were also made, and the production costs for trees were obtained in much the same way as were the grades and the value of the timber.

DETAILED DESCRIPTION OF METHODS FOLLOWED

The investigation was confined to shortleaf pine (*Pinus echinata*)[5] and loblolly pine (*P. taeda*), except at the study in western Arkansas where, in addition, white oak (*Quercus alba*), and red oak (including *Q. borealis maxima*, *Q. shumardii*, and *Q. velutina*) were given consideration.

The areas selected for study represented the following different forest conditions: (1) Second-growth, forest-grown, mixed shortleaf and loblolly pine; (2) second-growth old-field loblolly pine; (3) virgin shortleaf pine on flat land; and (4) virgin shortleaf pine and oak on mountain land.

Areas (2) and (4) were cut selectively whereas (1) and (3) were cut clear, except that in (1) and (3) a few 10-inch trees were left.

Second growth refers to trees that have grown from seeds after the cutting of the virgin timber, to small trees that were on the ground at the time of logging, and to timber that has come in from seed on abandoned farms. Usually such timber in this region is less than 75 years old.

Virgin growth designates timber in which there has been no logging. Ordinarily such timber, at present, averages nearly a century old, although the stand may contain trees ranging in age from 1-year seedlings to veterans more than 250 years old.

Old-field timber covers trees that have come in from seed on abandoned farms. It is considered second-growth timber.

Forest-grown second-growth timber applies to young stands on land that had been cut over but not cultivated.

Diameter, when applied to trees, in this bulletin, means the size outside the bark 4½ feet from the ground, and when applied to logs it means the average size at the small end inside the bark.

Site is an index of growth that is expressed as the average height of the dominant trees in the stand at the age of 50 years.

The Doyle log rule, the one employed by most lumbermen in the South, was used in the first three studies, whereas the Scribner decimal C, which is the official rule of the Forest Service, was required in the fourth study because that study was made on a national forest. The results of the fourth study, however, have been converted to a Doyle basis in order to make all the studies strictly comparable in this respect.

Figures 2 and 3 illustrate the woods work and the transportation.

Members of the study crew determined the time required for felling each tree and for bucking it into logs as it was handled by the two log cutters in the regular logging operation. The volume of each log was obtained by a scale rule. Production costs were computed as follows: Suppose the records showed that the log cutters required 60 minutes to produce 1,000 feet of logs from trees 20 inches in diameter, then if

[5] The names of species of wood appearing in this bulletin are those given in Miscellaneous Circular 92 (*6*).

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the men received 30 cents each per hour, the felling and bucking cost would be 60 cents per 1,000 board feet.

FIGURE 2.—Logging southern yellow pine: A, Felling trees; B, loading logs on wagons for hauling to the landing; C, logs bunched along a track spur ready for car loading.

The logs were skidded to the landing and loaded on wagons by the same men and teams that hauled them to the spur track. The time required to skid each log, the distance it was skidded, and the volume

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it contained were recorded. The same procedure was followed in loading. For hauling, the time required for the round trip, the distance traveled, and the volume hauled were recorded. These data when combined with the wages the men received and the cost of the

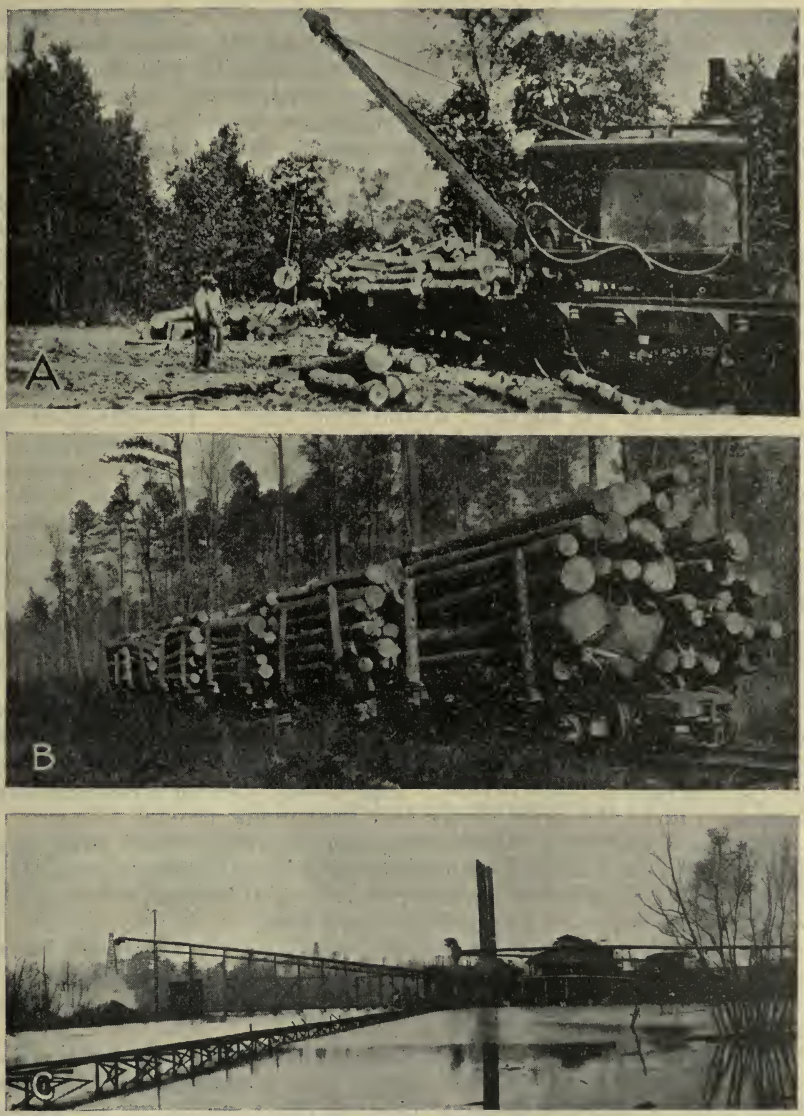

FIGURE 3.—The transportation and milling of southern yellow pine: A, Logs loaded with steamloaders; B, logs hauled by rail to the mill; C, most mills have their logs delivered direct to log pond.

teams made it possible to compute the skidding, loading, and hauling costs for logs of different sizes. The number of each log was also set down so that the cost of handling trees of different sizes could be computed.

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The cost of loading the logs on the railroad cars was determined by scaling each log and timing its loading. With this information and a knowledge of the cost of loading the unit cost for logs and trees of different sizes was easily computed.

The cost of hauling the logs to the mill obviously could not be determined from time records, so it was computed for logs of different sizes on the basis of the cost of a car trip and the various board-foot capacities of a standard car when loaded entirely with logs of one size. For example, a car when loaded with 8-inch logs will scale only about one half as much as when loaded with 26-inch logs. In this study the cost of hauling these cars to the mill was considered constant, regardless of the size of logs they contained, so the actual unit hauling cost would be twice as much for 8-inch logs as for 26-inch.

Unloading costs at the mill were determined directly from the wages paid the men who unloaded the cars and the volume handled. The unit cost of unloading for logs and trees of different sizes was computed from the time ratios established by the head saw in the mill, for the different sizes, and the average cost of unloading.

The investigation at the mill was carried on by a crew of five men so stationed as to obtain complete records for each log from the time when it came on the log deck to the time when it passed out of the mill on the green chain in the form of lumber. One man rescaled and renumbered the logs as they entered the mill, as a check on the woods work, and recorded their diameters, lengths, and woods number. A second man noted the time required to saw each log and the method of sawing. Another man placed the log number on each board, cant, or timber as it came from the head saw, so that the products from each log could be identified and tallied on the green chain. Finally, a lumber inspector and a tallyman graded and tallied the pine lumber and timber on the green chain for each log in accordance with the grading rules of the Southern Pine Association.

The cost of sawing lumber from logs of different sizes was computed from the actual time required by the mill to produce 1,000 board feet of lumber from logs of different diameters, and the average cost of running the mill for that period. The sawing cost for trees was computed by adding the costs for the logs that made up each tree.

Kiln, yard, and shed costs were obtained directly from each company and were considered to differ among the different sizes of logs in the same ratio as did the numbers of pieces of lumber, cut from the sizes, required to make a thousand board feet.

Planing-mill costs were considered constant per thousand board feet in this study because the planer can be adjusted to output, to a certain extent, and hence planer costs do not necessarily rise as the output of the mill decreases.

Shipping expense was obtained directly from the company's books, and the total cost has been distributed among the different diameter classes in accordance with the number of pieces of lumber for logs of different sizes required to make up a thousand board feet. General costs were also taken directly from company records, and the costs for trees of different sizes were computed from the average cost and the ratios established by the milling time.

Discount, taxes, and insurance were varied in accordance with the average prices of the lumber from each diameter class of logs or trees.

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Other costs, such as spur, road, and camp construction, were handled as fixed charges per acre, and under such conditions the cost per thousand board feet of lumber varies inversely with the amount of timber removed per acre. If an acre supports 10,000 board feet of timber and the railroad construction costs are $20 per acre, then the cost per thousand board feet would be $2, but if only 5,000 board feet are cut under selective logging the cost would be $4. It is thought that with improved logging methods the increase in the apportioned cost of permanent improvements that occurs when a part of the stand is left uncut, can be reduced appreciably.

The tables on production costs show the classification of each cost item and explain further the method of handling the items when computing the total costs for trees of different diameters and for different minimum cutting limits. Where the production costs for trees could not be obtained directly, as they were in felling, the costs for the logs that came from each tree were added together. Similarly, the volume and the value of the lumber from each tree were obtained by totaling the lumber that was sawed from the logs making up that tree. This method is feasible only when the same logs and trees are studied in the mill and in the woods, as was done throughout this investigation.

The change in grade and amount of the lumber that takes place between the green chain and the car was obtained by marking the grade on a representative volume of the lumber, and making subsequent tallies of the same lumber as it came from the kiln (7), after rough remanufacture, and also after finish-processing in the planer. The difference between the representative green-chain tally and the finished-lumber tally formed a basis for correcting the green-chain value of all the lumber to what it would be as finished lumber.

Lumber prices were obtained directly from each company. The value of the lumber for each diameter class was computed on the basis of a piece tally, by grades, adjusted for kiln drying and manufacturing changes, and with use of the appropriate lumber prices.

The average lumber value and production cost and the results when a stand was cut to different minimum-diameter limits were computed by using the distribution of the total volume among the different diameter classes as found at each study and shown in tables later on.

The lumber prices and wage scales used in this bulletin are based chiefly on 1929 averages. To adjust the production costs and lumber values given in this bulletin to conditions different from those obtaining during this period a straight-line percentage correction may be applied by diameter classes as explained on page 49.

PRESENTATION AND USE OF RESULTS

The discussion of production costs and lumber values given later is purposely confined to trees alone. Although much of the information was necessarily obtained through the study of logs, this was only a means to an end as far as this investigation was concerned. The real objective is to present figures for trees of different sizes. With figures on production costs, lumber values, and similar subjects available for individual trees, arranged by diameter classes, it is easy to assemble these unit data into values for a forest through the use of additional cruise figures giving the number by sizes of the trees in the stand.

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Figures for four separate operations are given in this bulletin, since the information when thus presented will be valuable to a greater number of operators than averages including all the operations would be. The guidance that the figures offer to a lumberman will depend to some extent on how closely the operations studied compare with his own. If his costs and lumber values are close to the study figures he may use the data without further computation; if they are not, he should take the basic figures shown herein and work out the results for his own conditions. Detailed instructions for doing this appear in later pages.

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE AREA STUDIED IN SOUTHERN ARKANSAS

The 17-acre tract of timberland in southern Arkansas selected for study supported a second-growth, forest-grown stand of shortleaf and loblolly pine averaging about 58 years in age. The area had not been cultivated, but a part of it had the appearance of having been partly cleared at some previous time, perhaps by a windstorm or by deadening. The volume was about equally divided between shortleaf and loblolly pine, and the results of the study are for the two species combined. Scattered among the pine trees were numerous small, unmerchantable hardwoods and a few hardwoods of merchantable size, but they were not included in the cut. On the average the tract supported 183 trees per acre, 100 of which were pine ranging in diameter breast-high from 4 to 26 inches, and 83 were small hardwoods, most of which were less than 10 inches in diameter although they ranged in size from 1 inch up to 20 inches. Considering only the pine the area was classified as an 80-foot site.[6] The average height of the dominant shortleaf pine at the time of the study was 82 feet and the loblolly pine 85 feet. The tract was only 60 percent fully stocked on a volume basis according to the figures given in Miscellaneous Publication 50 (*8*).

The area had been burned over several times, how often is unknown, but the fires had apparently been mild, for the damage was not excessive. Only 1¼ percent of the trees showed fire scars, and the total loss in the stand from defect, which included crook, rot, fire scarring, breakage, and operating damage, amounted to only 3.4 percent; this loss was determined by the difference between gross and net scale. Defect loss rose from 1.1 percent for 8-inch trees to a maximum of 4.8 percent for 12-inch, and then declined to 2.1 percent for the 24-inch class.

Practically all the pine 8 inches in diameter and larger was cut for saw logs, but none of the hardwoods was removed, although a number of the smaller trees were broken down in logging. The area, after the logging, would be classified as clear cut.

A total of 153,323 board feet, gross log scale, of shortleaf and loblolly pine, or 9,000 board feet per acre, was cut from the tract. The logs average 44 board feet each, or about 23 logs to the thousand board feet, and ranged in diameter from 7 to 20 inches and in length from 12 to 20 feet. The average diameter of the logs, as calculated from the volume of the cut, was about 11 inches and that of the trees about 15 inches.

[6] Site is measured by the height of the average dominant tree at the age of 50 years.

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The cut was made up of trees ranging in size from 8 to 26 inches in diameter breast high. Since production costs and lumber quality differ among the different diameters it is important in arriving at an average to know the volume in each diameter class. Table 1 gives the volume distribution of the cut among the trees of different size on a gross log scale and also on a lumber-tally basis. The figures in this table show that 65 percent of the cut came from trees 13 to 18 inches in diameter and that the volume harvested diminishes to an extremely small proportion of the whole in the lower and the upper diameters. Further, these figures are used later on in computing weighted-average production costs, lumber values, and the results that would have come if a part of the stand had been left uncut, as is done in selective logging.

TABLE 1.—*Distribution among the different sizes of second-growth, forest-grown mixed shortleaf and loblolly pine trees, by gross log scale and lumber tally, of the volume of timber cut in southern Arkansas*

Diameter breast high	Volume distribution		Diameter breast high	Volume distribution	
	Gross log scale	Lumber tally		Gross log scale	Lumber tally
Inches	*Percent*	*Percent*	*Inches*	*Percent*	*Percent*
8	0.1	0.2	18	8.6	7.8
9	1.1	1.9	19	6.8	6.0
10	2.4	3.6	20	5.1	4.5
11	4.1	5.3	21	3.6	3.1
12	6.6	7.5	22	2.4	2.1
13	10.0	10.6	23	1.5	1.3
14	11.8	12.0	24	.8	.7
15	12.2	12.0	25	.4	.3
16	11.9	11.3	26	.1	.1
17	10.5	9.7			

SECOND-GROWTH OLD-FIELD LOBLOLLY PINE AREA STUDIED IN NORTHERN LOUISIANA

The 13-acre area selected for study in northern Louisiana was a typical old-field stand. It had been farmed in the late eighties by the man who logged it in 1930. On the average the stand was 42 years old, but individual trees as young as 25 years were found, and a few trees around the edge of the cutting area were over 50 years old. There were also on the area a few shortleaf pine trees, the volume of which did not exceed 6 percent of the total cut, and a few longleaf pines that were excluded from the results; for practical purposes the timber may be classed as loblolly pine. In addition, a few small, scattering, unmerchantable hardwoods were growing on the area, but they were of no importance and may be ignored except in connection with cultural thinnings.

The study area, which was classified as an 80-foot site, supported timber equal to about 80 percent of the volume of a fully stocked stand. There were an average of 207 pine trees per acre, ranging in size from 4 to 26 inches in diameter breast high (fig. 4). The trees cut for lumber during the study ranged in size from 8 to 26 inches in diameter and those that were left standing ranged from 4 to 18 inches. The timber 8 inches and larger in diameter aggregated 10,133 board feet, gross log scale, or 17,259 board feet, lumber tally, per acre for the study area. In the selective-cutting plan followed, 77 percent of this

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volume was removed from the entire area, or a grand total of 179,209 board feet, lumber tally. The trees that were cut averaged 119 board feet each, log scale, and the logs 44 board feet, log scale, or 23 logs to the thousand board feet. The logs averaged about 11 inches in diameter inside the bark and the trees about 16 inches in diameter outside the bark, according to calculations based on the volume of the cut.

The area had been burned over several times, but the damage was not excessive, even though 6.4 percent of the trees showed indications of butt rot. Forked trees were very noticeable in the stand, amounting to 3.3 percent by volume of the cut. Counting all imperfections for which a reduction in scale was made, such as cat face, crook, and rot, the loss amounted to only 1.3 percent.

Table 2 shows the volume distribution, among the different diameter classes, of the timber cut. As might be expected in a second-growth old-field stand, nearly 50 percent of the volume was concentrated in the 14- to 17-inch diameter classes.

TABLE 2.—*Distribution among the different sizes of second-growth old-field loblolly pine trees, by gross log scale and lumber tally, of the volume of timber cut in northern Louisiana*

Diameter breast high	Volume distribution		Diameter breast high	Volume distribution	
	Gross log scale	Lumber tally		Gross log scale	Lumber tally
Inches	*Percent*	*Percent*	*Inches*	*Percent*	*Percent*
8	0.1	0.2	18	9.2	8.4
9	.2	.4	19	6.9	6.2
10	.7	1.1	20	5.2	4.5
11	2.6	3.6	21	4.0	3.4
12	5.8	7.2	22	3.2	2.7
13	8.9	10.2.	23	2.4	2.0
14	11.1	11.9	24	1.8	1.4
15	12.2	12.4	25	1.2	.9
16	12.5	12.2	26	.6	.5
17	11.4	10.8			

VIRGIN SHORTLEAF PINE AREA STUDIED IN THE FLATLANDS OF EASTERN TEXAS

Two areas in eastern Texas about one fourth mile apart, representing different classes of timber, were studied. The stand on one area, which was 6½ acres in extent, consisted chiefly of large, old, shortleaf pines; the small pines were fewer in number than is common, but about the average number of small, scattered, poor-quality hardwoods were growing. None of these hardwoods, which were mainly red gum, hickory, black and willow oak, and red and white oak, were cut in this study. The pine averaged 43.8 trees per acre, ranging in size from 4 to 31 inches in diameter breast high and in age from young growth 10 to 20 years old to veterans of more than 250 years. The pine trees that were cut, which ranged from 40 to 274 years in age, averaged 122 years. Their average height was 107 feet and average diameter 20.2 inches. The area was classified as an 80-foot site; considering the pine only, it was about 40 percent fully stocked. There were 25.4 hardwood trees per acre, ranging in size from 4 to 21 inches, with most of them less than 12 inches in diameter. The second area, about 12 acres in extent, was covered with a virgin stand, but the trees were thicker on the ground and were younger than those on the other area. Like the first area, it contained a few small hard-

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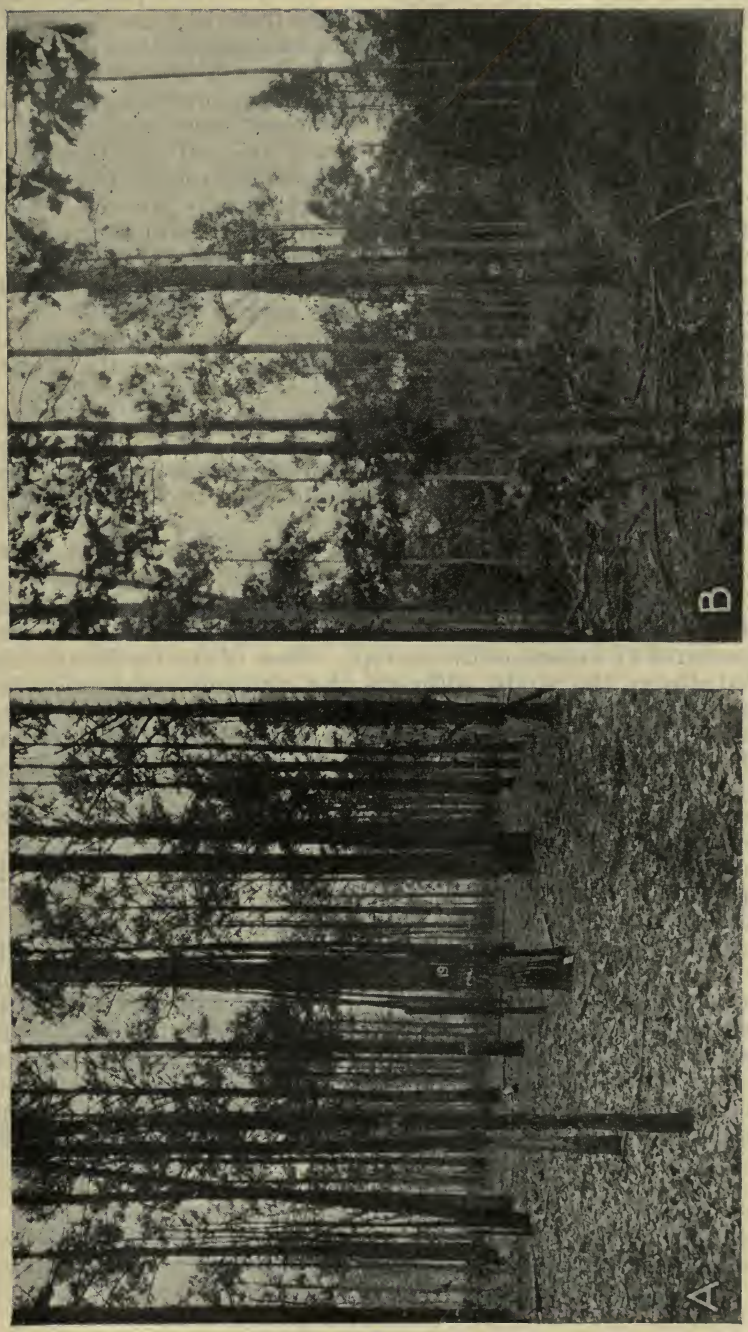

FIGURE 4.—Selective cutting in an old-field loblolly pine stand; (A), Before logging; (B), after logging.

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woods of poor quality; the same species appeared, and elm was there in addition. The average number of trees was 128.9 per acre; they ranged from 4 to 28 inches in diameter and from 10 to more than 150 years of age. The pine trees that were cut ranged from 40 to 152 years and averaged 74 years old. The average height of all trees in the stand was 85 feet, and the average diameter breast high was 15.6 inches. The average height of the dominant trees was about 100 feet; the area was classified as between a 70- and an 80-foot site, which made it approximately the same as the first plot. Considering the pine only, the area was about 70 percent fully stocked. There were 9.4 hardwood trees per acre, ranging from 4 to 19 inches in diameter; over two thirds of them were less than 12 inches in diameter.

The combination of these two areas should give a good average for the virgin-growth flatland shortleaf pine areas. The stand on the two areas gave some evidence of fire injury, but judging from the underbrush the area had not been burned over during the 5 years preceding the study. Nine percent of the trees showed fire scars.

The oldest trees on the larger area showed an increase in growth about 70 years ago, indicating that the stand had been thinned out at that time. Since there had been no previous cutting on the area the most logical explanation is that a windstorm had blown down a part of the stand.

All but 2 trees per acre, of those 10 inches or more in diameter breast high, were cut for saw logs on the small plot, while on the larger area 23 such trees were left per acre. This cutting policy corresponded with the general practice of the company to take almost all the trees that measured 12 inches on the stump. None of the hardwoods was removed during the study, although the company's general policy was to cut the hardwoods that could be used, along with the pine. The hardwoods on these areas were of so little importance in the logging that they would have had practically no effect on the financial aspects of the operation.

There was a small amount of loblolly pine (7.5 percent) in mixture, but for all practical purposes the stand could well be considered a pure shortleaf type, and hereafter no mention will be made of the other pine.

A total of 198,938 board feet, gross log scale, of shortleaf pine, or about 10,600 board feet per acre, was cut from the 18.72 acres of the two tracts. The trees that were cut averaged 242 board feet each. The logs, which ranged in length from 10 to 20 feet, ran 12½ to the thousand or 80 board feet each. The average log was about 13 inches in diameter inside the bark and the average tree 17 inches in diameter breast high outside the bark.

Table 3 shows the volume distribution of the timber studied among the different diameter classes on gross-log scale and lumber-tally bases.

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TABLE 3.—*Distribution among the different sizes of virgin-growth flatland shortleaf pine trees, by gross log scale and lumber tally, of the volume of timber cut in eastern Texas*

Diameter breast high	Volume distribution		Diameter breast high	Volume distribution	
	Gross log scale	Lumber tally		Gross log scale	Lumber tally
Inches	*Percent*	*Percent*	*Inches*	*Percent*	*Percent*
10	0.1	0.2	21	6.0	5.5
11	1.1	1.6	22	5.5	5.0
12	3.1	4.1	23	5.0	4.4
13	5.1	6.3	24	4.5	3.9
14	6.9	8.1	25	4.0	3.4
15	8.6	9.5	26	3.5	2.9
16	8.6	9.2	27	2.9	2.4
17	8.1	8.3	28	2.4	1.9
18	7.5	7.5	29	1.8	1.4
19	7.0	6.8	30	1.2	.9
20	6.5	6.2	31	.6	.5

VIRGIN SHORTLEAF PINE AND MIXED OAK AREA STUDIED IN THE MOUNTAINS OF WEST-CENTRAL ARKANSAS

A rectangular area in the Ouachita National Forest, which extended from bottom land along a stream course up a slope to a ridge top about 500 feet high, was selected for study; it was 53.8 acres in extent. The shortleaf pines on this area averaged 68 trees to the acre; they ranged in diameter breast high from 4 to 29 inches. In age they ran from seedlings to trees more than 250 years old. The hardwoods averaged 2 merchantable trees per acre, 12 inches and more in diameter, and a count of a 12-acre tract within the cutting area showed that there were 34 trees per acre below this size, mostly in the 4- and 6-inch classes. The average age of the trees that were cut was 144 years, and the average total height 76 feet.

For the tract as a whole, the site index was estimated as 60. Considering the shortleaf pine only, the stand was only about one third fully stocked. The area was better stocked on the lower part than on the upper slopes, principally because of better soil and less fire damage. The stand averaged 4,558 board feet, gross log scale, of shortleaf pine and about 240 board feet of hardwoods, 8 inches and larger, per acre. Counting all imperfections for which a reduction in scale was made, such as cat face, crook, and rot, the loss amounted to 8.2 percent.

The aim was to remove all the mature dominant trees, the slow-growing or inferior intermediate ones, and defective trees of all classes, and to leave enough thrifty ones of various sizes, well distributed over the area (fig. 5), to equal 30 percent of the volume of the original stand, in order both to seed the area and to provide another cut in about 35 years; 54 shortleaf pine trees per acre, ranging in size from 4 to 24 inches in diameter, were left standing for these two purposes. The plan called for cutting all merchantable hardwood trees. On 12 acres of this particular area the remaining unmerchantable hardwoods were girdled or poisoned by the Southern Forest Experiment Station as an experiment in an effort to rid the land of them and thus make room for healthy trees of either pine or hardwood.

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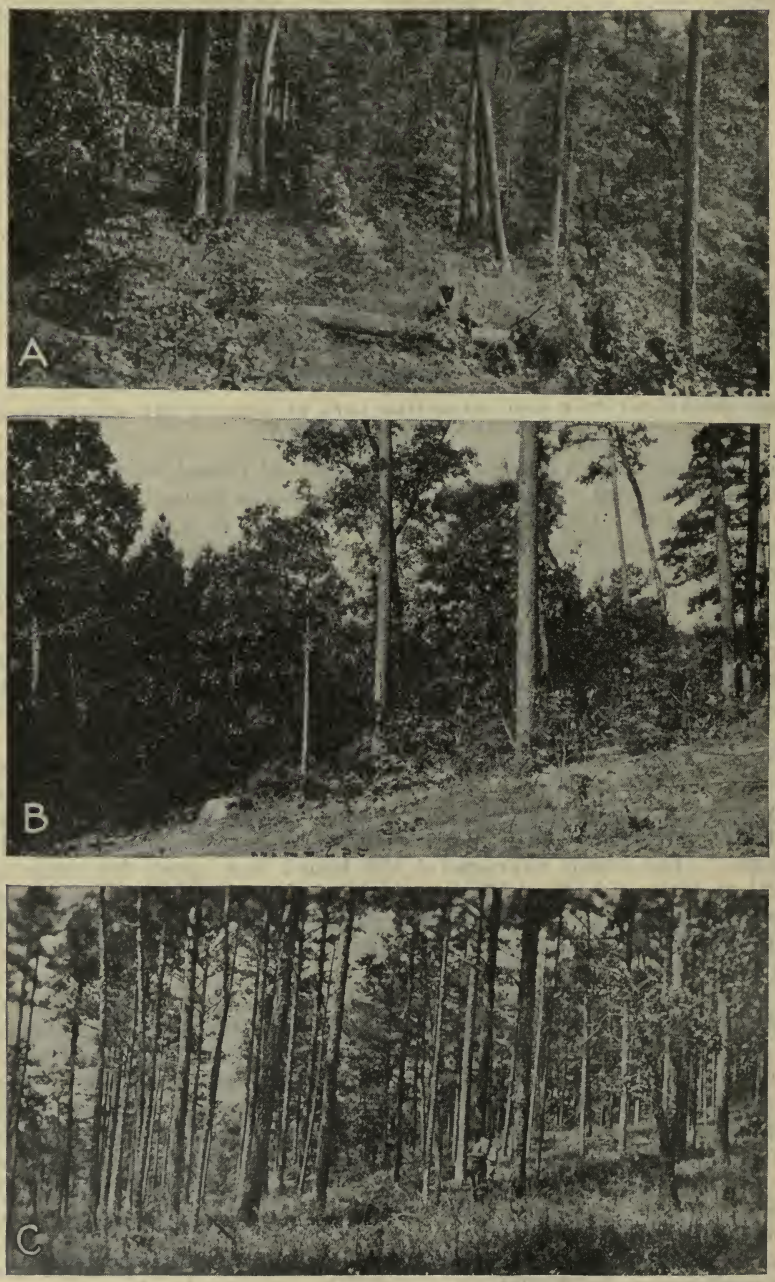

FIGURE 5.—Selective cutting in the Ouachita National Forest. (A) Virgin stands of shortleaf pine (B) cut selectively indicate that (C) young growth will come in under such management.

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TABLE 4.—*Distribution among the different sizes of virgin-growth mountain shortleaf pine trees, by gross log scale and lumber tally, of the volume of timber cut in west-central Arkansas, and also the total number of trees cut and left*

Diameter breast high, inches	Trees			Defective trees in the cut	Volume distribution	
	Total	Cut	Left		Gross log scale	Lumber tally
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
4	976		976			
5	607		607			
6	343		343			
7	263		263			
8	136		136			
9	56	2	54	11.1		0.1
10	77	24	53	10.5	0.3	.5
11	103	45	58	9.9	1.1	1.5
12	126	54	72	9.3	2.0	2.6
13	146	69	77	8.8	3.1	3.9
14	137	70	67	8.6	4.7	5.5
15	128	69	59	8.2	6.4	7.2
16	125	73	52	8.2	8.2	8.9
17	124	84	40	7.8	10.0	10.4
18	94	66	28	7.4	11.6	11.7
19	65	47	18	7.1	12.5	12.2
20	54	44	10	7.6	11.8	11.2
21	46	39	7	7.8	9.4	8.6
22	29	24	5	8.3	6.7	5.9
23	13	8	5	8.9	4.5	3.8
24	7	6	1	9.6	2.9	2.4
25	6	6		10.7	1.8	1.4
26	1	1		11.4	1.2	.9
27	1	1		12.2	.9	.7
28	1	1		13.0	.6	.4
29	1	1		14.3	.3	.2
Total	3,665	734	2,931			
Trees per acre	68	14	54			
Average				8.2		

Table 4 shows the total number of shortleaf pines on the tract, the proportions that were cut and that were left, and the volume distribution among the different diameter classes of the trees cut, both on a gross-log-scale and a lumber-tally basis. There were only 68 pine trees per acre; this is a light stand even with the addition of the few hardwoods that were in mixture. On the average, the 14 shortleaf pine trees cut per acre yielded 4,161 board feet, lumber tally, and in addition the 2 oak trees yielded 286 board feet, a total of 72 percent of the volume of the total stand 8 inches and larger. About 81 percent of the cut came from trees 14 to 22 inches in diameter; the largest volume was from the 19-inch diameter class, which supplied 12.5 percent of the total volume cut.

LOGGING AND MILLING CONDITIONS

All the study areas, with the exception of that in west-central Arkansas, were fairly level, and were well drained; the soil was sandy clay, its surface free from rocks. The surface of the study area in west-central Arkansas varied from smooth, flat land in the lower part to steep, rocky stretches on the sides and the tops of the ridges. The soil was a fine white clay in the bottoms and almost a pure gravel on the slopes and ridges. The rainfall and logging conditions for the period were normal on all areas.

The trees were felled, limbed, and bucked into log lengths by crews of two men each. The logs were skidded to the wagons by the hauling crews, loaded by "cross haul", and transported to the spur track

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with wide-tired wagons. The hauling distance in the southern Arkansas, Louisiana, Texas, and west-central Arkansas operations averaged 740; 1,925; 1,150; and 1,593 feet, respectively. All logs were loaded singly on standard-gage cars with a steam loader. The railroad haul from the stands to the mills, in the foregoing order, was 11, 20, 56, and 75 miles, respectively.

All mills had band head saws and complementary equipment, such as edgers and trimmers, but had no resaws. Under ordinary practice at the southern Arkansas and Louisiana mills the no. 2 common and better lumber was kiln-dried and the no. 3 common was air-seasoned. At the Texas mill the higher quality no. 2 common and better lumber was kiln-dried and the low-quality no. 2 common and the no. 3 common was air-seasoned. Occasionally, on rush orders, small and medium-sized timbers were put through the kilns. All the lumber at the west-central Arkansas mill was kiln-dried and was then put through the rip mill for such additional manufacture as was necessary before storage in the dry shed. Practically all the lumber at all the mills was either surfaced or run to pattern before being shipped.

LOGGING COSTS PER THOUSAND BOARD FEET, GROSS LOG SCALE

The increased unit cost and the decreased output when handling small trees instead of large ones are not so apparent to the casual observer when he is in the woods as when he is in the mill, but they exist, nevertheless. Table 5 shows the weighted-average unit cost by items for logging all trees together and the corresponding costs for each diameter class. With the exception of the items for spur tracks and the various camps the unit production costs are greater, in all items for small trees than for large ones. Sawing down the trees and cutting them into logs costs more than three times as much per thousand board feet, gross log scale, for trees 10 inches in diameter as for trees 24 inches in diameter. Loading, freight, and skidding costs show similar relations. Summing up all items, it costs nearly three times as much to cut the logs from 10-inch trees and bring them to the mill as to handle the logs from 24-inch trees. Because of the larger overrun for small trees, however, this ratio and others like it are reduced somewhat when the cost figures are converted to a lumber-tally basis by means of overrun percentages, but the general fact remains unchanged; unit production costs are higher for small trees than for large ones. The grouping of the items in table 5 is somewhat different for each operation because of the different methods of cost keeping employed by the cooperating lumber companies.

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TABLE 5.—*Logging costs per thousand board feet, gross log scale and lumber tally, by diameter classes for the 4 operations studied*

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE TREES, SOUTHERN ARKANSAS

Cost item	Classification of cost [1]	Weighted average cost per thousand board feet, gross log scale	Itemized costs per thousand board feet, gross log scale, for the indicated diameter breast high, in inches—																							
			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Sawing	VT	1.20	4.50	2.91	2.23	1.82	1.53	1.37	1.25	1.15	1.07	1.02	0.98	0.95	0.93	0.92	0.90	0.90	0.89	0.88	0.87	----	----	----	----	----
Skidding and wagon haul	VT	1.40 } 1.79	10.09	6.02	4.56	3.45	2.74	2.26	1.92	1.68	1.49	1.33	1.21	1.09	1.01	.95	.89	.84	.80	.76	.74	----	----	----	----	----
Swamping	VT	.31																								
Scaling	VT	.08																								
Loading on cars	VT	.81	4.21	3.24	2.44	1.82	1.38	1.07	.87	.73	.62	.54	.47	.42	.38	.34	.31	.28	.26	.25	.24	----	----	----	----	----
Freight on cars	V Cap	1.53	4.46	3.73	3.08	2.50	2.08	1.82	1.63	1.48	1.37	1.27	1.19	1.12	1.06	1.01	.97	.94	.91	.89	.88	----	----	----	----	----
Supplies and repairs	V Tot	.16 } .64	2.79	1.91	1.48	1.15	.93	.78	.68	.61	.55	.50	.46	.43	.41	.39	.37	.36	.34	.33	.33	----	----	----	----	----
Depreciation, insurance, and taxes on woods equipment	V Tot	.18																								
General expense	V Tot	.30																								
Spur tracks	CA	1.80 } 1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	----	----	----	----	----
Camps	CA	.13																								
Total logging cost per thousand board feet, gross log scale	----	7.90	27.98	19.74	15.72	12.67	10.59	9.23	8.28	7.58	7.03	6.59	6.24	5.94	5.72	5.54	5.37	5.25	5.13	5.04	4.99	----	----	----	----	----
Total logging cost per thousand board feet, lumber tally	----	5.62	10.95	8.73	7.89	7.29	6.78	6.25	5.81	5.48	5.19	4.95	4.76	4.59	4.45	4.34	4.24	4.16	4.08	4.03	4.01	----	----	----	----	----

SECOND-GROWTH OLD-FIELD LOBLOLLY PINE TREES, NORTHERN LOUISIANA

Sawing; labor, scaling, and expenses	VT	1.10	8.16	4.78	3.10	2.28	1.84	1.53	1.29	1.11	0.97	0.87	0.82	0.77	0.74	0.71	0.70	0.69	0.68	0.68	0.68	----	----	----	----	----
Hauling; labor, scaling, and expenses	VT	3.47	14.48	11.76	9.55	7.64	6.07	4.95	4.14	3.55	3.11	2.77	2.54	2.35	2.23	2.12	2.04	1.97	1.91	1.87	1.83	----	----	----	----	----
Loading on cars:																										
Labor	VT	0.64 } .78	7.39	5.00	3.49	2.41	1.72	1.25	.96	.76	.63	.53	.47	.41	.36	.33	.30	.26	.24	.22	.20	----	----	----	----	----
Expense	VT	.14																								

[1] Code for classification of costs: CA = constant per acre; V Cap = varies with the capacity of the cars when they are loaded with logs of 1 size only; VMT = varies with the time in the mill; VT = varies with the time per thousand board feet required for logs from trees of different sizes; V Tot = varies with the sum of the other logging costs, excluding CA costs.

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TABLE 5.—*Logging costs per thousand board feet, gross log scale and lumber tally, by diameter classes for the 4 operations studied*—Contd.

SECOND-GROWTH OLD-FIELD LOBLOLLY PINE TREES, NORTHERN LOUISIANA—Continued

Cost item	Classification of cost	Weighted average cost per thousand board feet, gross log scale	Itemized cost per thousand board feed, gross log scale, for the indicated diameter breast high, in inches—																							
			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Spur tracks; labor and expense	CA	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	-----	-----	-----	-----	-----
Railroad transportaion:																										
Railroad labor	V Cap	.69 } 2.18	6.43	5.49	4.61	3.87	3.25	2.79	2.47	2.24	2.05	1.94	1.82	1.73	1.66	1.59	1.52	1.45	1.38	1.31	1.25	-----	-----	-----	-----	-----
Railroad expense	V Cap	1.49																								
Railroad maintenance	VMT	.35	1.66	1.24	.92	.70	.57	.46	.39	.36	.31	.30	.28	.27	.25	.25	.24	.24	.23	.22	.21	-----	-----	-----	-----	-----
Woods supervision	V Tot	.34	1.64	1.22	.94	.73	.58	.47	.40	.35	.31	.28	.26	.24	.23	.22	.21	.20	.19	.19	.18	-----	-----	-----	-----	-----
Total logging cost per thousand board feet, gross log scale	----------	10.20	41.74	31.47	24.59	19.61	16.01	13.43	11.63	10.35	9.36	8.67	8.17	7.75	7.45	7.20	6.99	6.79	6.61	6.47	6.33	-----	-----	-----	-----	-----
Total logging cost per thousand board feet, lumber tally	----------	6.65	12.33	11.25	10.41	9.55	8.64	7.80	7.17	6.67	6.24	5.92	5.70	5.50	5.39	5.29	5.20	5.14	5.07	5.03	4.99	-----	-----	-----	-----	-----

VIRGIN-GROWTH FLATLAND SHORTLEAF PINE TREES, EASTERN TEXAS

Sawing:																										
Labor	VT	1.16 } 1.18	-----	-----	2.12	1.92	1.74	1.59	1.46	1.36	1.28	1.21	1.16	1.11	1.08	1.04	1.02	1.00	0.98	0.96	0.94	0.92	0.91	0.89	0.87	0.86
Material and supplies	VT	.02																								
Skidway and teamsters:																										
Labor	VT	.93 } 2.00	-----	-----	6.42	5.32	4.37	3.63	3.10	2.67	2.33	2.07	1.85	1.67	1.54	1.42	1.32	1.24	1.19	1.13	1.09	1.05	1.01	.98	.96	.94
Material and supplies	VT	.24																								
Animal feed	VT	.83																								
Loading:																										
Labor	VT	.46 } .59	-----	-----	2.33	1.90	1.49	1.19	.97	.81	.70	.60	.53	.47	.42	.38	.35	.32	.30	.28	.26	.25	.24	.22	.21	.20
Material and supplies	VT	.13																								
Railroad transportation:																										
Woods engine:																										
Labor	V Cap	.59 } 3.50	-----	-----	8.13	7.04	6.16	5.39	4.79	4.29	3.87	3.59	3.31	3.13	2.96	2.85	2.75	2.68	2.60	2.53	2.46	2.39	2.32	2.25	2.18	2.11
Material and supplies	V Cap	.48																								
Main logging road	V Cap	2.43																								

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Spur track:																											
Labor	CA	1.39	1.54	-----	-----	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.94	1.54	1.54	1.54	1.54
Material and supplies	CA	.15																									
Miscellaneous logging expenses	V Tot		.55	-----	-----	1.44	1.22	1.04	.89	.78	.69	.62	.57	.52	.48	.45	.43	.41	.40	.38	.37	.36	.35	.34	.33	.32	.31
Total logging cost per thousand board feet, gross log scale	---------		9.36	-----	-----	21.98	18.94	16.34	14.23	12.64	11.36	10.34	9.58	8.91	8.40	7.99	7.66	7.39	7.18	6.99	6.81	6.65	6.50	6.36	6.21	6.08	5.96
Total logging cost per thousand board feet, lumber tally	---------		6.98	-----	-----	11.05	10.21	9.44	8.77	8.22	7.74	7.30	7.00	6.67	6.43	6.23	6.08	5.96	5.89	5.83	5.77	5.71	5.66	5.61	5.56	5.52	5.48

VIRGIN-GROWTH MOUNTAIN SHORTLEAF PINE TREES, WEST-CENTRAL ARKANSAS

Sawing:																											
Labor	VT	1.07	1.27	-----	5.39	4.39	3.55	2.87	2.34	1.95	1.65	1.46	1.28	1.16	1.07	1.00	0.94	0.90	0.87	0.86	0.83	0.83	0.82	0.81	0.79	-----	-----
Tools and supplies	VT	.02																									
Scaling and supervision	VT	.18																									
Brush disposal	VT		.48	-----	2.72	2.09	1.57	1.21	.94	.77	.65	.56	.49	.43	.40	.35	.33	.32	.29	.28	.27	.26	.25	.24	.23	-----	-----
Skidding, wagon haul, and swamping	VT	3.57	3.65	-----	18.01	14.22	11.33	9.11	7.37	6.04	5.06	4.35	3.79	3.35	3.02	2.73	2.50	2.31	2.18	2.07	1.99	1.94	1.91	1.90	1.89	-----	-----
Scaling	VT	.08																									
Loading on cars	VT		1.41	-----	8.46	6.70	5.25	4.11	3.25	2.61	2.15	1.81	1.54	1.30	1.10	.94	.79	.70	.60	.54	.48	.44	.42	.40	.39	-----	-----
Spur track and camps	CA		1.92	-----	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	-----	-----
Main-line maintenance, train labor, and supplies	VMT		1.19	-----	2.98	2.61	2.31	2.06	1.85	1.66	1.54	1.41	1.30	1.20	1.10	1.01	.93	.87	.80	.75	.71	.68	.66	.65	.63	-----	-----
Freight	V Cap		1.60	-----	4.48	3.79	3.22	2.75	2.41	2.13	1.96	1.81	1.67	1.56	1.47	1.40	1.33	1.28	1.23	1.19	1.16	1.13	1.12	1.10	1.08	-----	-----
Salaries	V Tot	.09	1.55	-----	6.79	5.46	4.40	3.57	2.93	2.45	2.10	1.84	1.63	1.45	1.32	1.20	1.10	1.03	.96	.92	.88	.85	.84	.82	.81	-----	-----
Office expense	V Tot	.01																									
Liability insurance	V Tot	.16																									
Group life insurance	V Tot	.01																									
Motor-car repairs and supplies	V Tot	.19																									
Miscellaneous expense	V Tot	.22																									
Fire and locomotive insurance	V Tot	.01																									
Taxes on logging equipment and railroad	V Tot	.08																									
Depreciation	V Tot	.78																									
Total logging cost per thousand board feet, gross log scale	---------		13.07	-----	50.75	41.18	33.55	27.60	23.01	19.53	17.03	15.16	13.62	12.37	11.40	10.55	9.84	9.33	8.85	8.53	8.24	8.05	7.94	7.84	7.74	-----	-----
Total logging cost per thousand board feet, lumber tally	---------		10.13	-----	23.94	21.17	18.77	16.60	14.71	13.15	11.91	10.95	10.16	9.53	9.01	8.56	8.20	7.99	7.79	7.73	7.69	7.71	7.83	7.96	8.10	-----	-----

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EFFECT OF OVERRUN ON PRODUCTION COSTS

Logging costs are generally kept on a log-scale basis and milling costs on a lumber-tally basis. Since total costs are ordinarily computed in accordance with the lumber tally, it is necessary to convert logging costs into lumber-tally values, and this is done by means of overrun figures. Gross overrun is the amount by which the lumber tally exceeds the gross log scale. Correction is needed because the Doyle log-scale rule does not give the true lumber content of logs. This is partly the fault of the rule and partly because the efficiency of the mill and the percentages of the different thicknesses of lumber sawed, both of which affect the volume obtained from logs, cannot be predetermined by any rule.

Table 6 shows the gross overrun, arranged by tree diameter, for the four operations studied. The overrun is extremely high in the smaller trees because the Doyle log rule gives values disproportionately lower for small logs than for large ones. Small trees yield more lumber per thousand board feet, log scale, than do large ones; in this way they compensate in part for the higher unit cost of handling them. For example, the felling and bucking cost for the logs from 9-inch trees in southern Arkansas (table 5) was 3.1 times that for 20-inch trees on a log-scale basis, but when the costs are changed to a lumber-tally basis by dividing them by 100 percent plus the appropriate overrun percentage, expressed as a decimal fraction (for 9-inch trees, $\frac{\$2.91}{2.42}=\$1.20$; for 20-inch, $\frac{\$0.93}{1.23}=\$0.76$), the ratio is reduced to 1.6. The overrun figures are based on the lumber tally at the green chain. The total amount of green lumber is reduced by the losses in quantity that occur in seasoning, remanufacture, and planing, but the effect of these losses has been taken care of by using, as the value of a thousand board feet of green lumber, the price actually received for the smaller amount of dry, manufactured lumber obtained from it.

TABLE 6.—*The overrun for the four operations studied*

GROSS OVERRUN

Diameter breast high, inches	Southern Arkansas [1]	Northern Louisiana [2]	Eastern Texas [3]	West-central Arkansas [4]
	Percent	*Percent*	*Percent*	*Percent* [5]
8	172.0	260.0	----------	----------
9	142.0	196.0	----------	117.5
10	111.5	148.0	106.5	99.5
11	81.5	113.5	92.0	83.0
12	60.0	91.0	78.5	70.0
13	49.5	76.0	66.5	59.5
14	43.0	64.0	57.0	51.0
15	37.5	55.5	49.0	45.0
16	33.5	49.0	43.0	40.0
17	30.0	44.5	37.5	35.0
18	27.0	40.5	33.5	30.0
19	24.5	37.0	30.0	26.0
20	23.0	33.5	27.0	22.0
21	21.5	30.5	24.0	18.0
22	20.0	28.0	21.5	14.0
23	19.0	25.0	19.0	10.0
24	18.0	22.5	16.5	6.0
25	17.0	20.0	14.0	2.0
26	16.0	17.5	12.0	−1.5
27	----------	----------	10.0	−5.0
28	----------	----------	8.0	−8.5
29	----------	----------	6.0	−12.0
30	----------	----------	4.0	----------
31	----------	----------	2.0	----------
Weighted average	40.4	53.2	34.1	29.0

[1] Second-growth, forest-grown mixed shortleaf and loblolly pine.
[2] Second-growth old-field loblolly pine.
[3] Virgin-growth flatland shortleaf pine.
[4] Virgin-growth mountain shortleaf pine.
[5] Minus sign indicates a loss.

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Total unit logging costs, both the average value and the values for individual tree diameters, have been obtained by merely adding up the unit costs of the different logging items. The unit costs of the spur tracks and of the camps vary with the total amount of timber removed from each acre. For the purpose of computing the production costs by diameter classes, however, these two charges have been considered as being the same per thousand board feet for each diameter class of the trees as for all sizes together; therefore, in converting these charges to a lumber-tally basis, the average overrun is used and not the overrun for individual tree sizes, as was done with the other cost items.

All the logging costs shown in the following tables have been converted to a lumber-tally basis by means of the overrun figures in table 6. From here on production costs for this operation will be discussed in terms of lumber tally only.

TOTAL UNIT LUMBER-PRODUCTION COST

To a large extent the unit cost in the mill is governed by the output of the head saw, because the mills are equipped and manned to produce a certain amount of lumber and the cost per day is more or less fixed. Therefore, the unit costs are low when the output is high and high when the output is low. For this reason careful time studies were made at the head saw to determine the comparative time required to produce 1,000 board feet of lumber from logs of different sizes. It was found that more time was required to saw 1,000 feet of lumber from small logs than to saw the same amount from large logs, and hence the costs were higher. The time ratios among the different diameter classes have been used in the computation of sawing costs and several other unit costs connected with milling.

With logging costs converted to a lumber-tally basis, the total unit production costs may be obtained by adding the unit-logging and the unit milling costs, which were recorded on this basis. Such addition has been made, and the total average unit production cost and the equivalent costs for shortleaf and loblolly pine trees of different diameters are shown in table 7.

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TABLE 7.—*Production costs* [1] *per thousand board feet, lumber tally, by diameter classes for the four operations studied*

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE TREES, SOUTHERN ARKANSAS

Cost item	Classification of cost [2]	Weighted average cost per thousand board feet, lumber tally	Itemized costs for the indicated diameter breast high in inches																							
			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Sawing	VT	0.85	1.65	1.20	1.05	1.00	0.96	0.92	0.87	0.84	0.80	0.78	0.77	0.76	0.76	0.76	0.75	0.76	0.75	0.75	0.75	-----	-----	-----	-----	-----
Skidding and wagon haul	VT	0.99																								
Swamping	VT	.22 } 1.27	3.71	2.49	2.16	1.90	1.71	1.51	1.34	1.22	1.12	1.02	.95	.88	.82	.78	.74	.71	.68	.65	.64	-----	-----	-----	-----	-----
Scaling	VT	.06																								
Loading on cars	VT	.58	1.55	1.34	1.15	1.00	.86	.72	.61	.53	.46	.42	.37	.34	.31	.28	.26	.24	.22	.21	.21	-----	-----	-----	-----	-----
Freight on cars	V Cap	1.09	1.64	1.54	1.46	1.38	1.30	1.22	1.14	1.08	1.03	.98	.94	.90	.86	.83	.81	.79	.77	.76	.76	-----	-----	-----	-----	-----
Supplies and repairs	V Tot	.11																								
Depreciation, insurance, and taxes on woods equipment	V Tot	.13 } .46	1.03	.79	.70	.63	.58	.52	.48	.44	.41	.38	.36	.35	.33	.32	.31	.30	.29	.28	.28	-----	-----	-----	-----	-----
General expense	V Tot	.22																								
Spur tracks	CA	} 1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	-----	-----	-----	-----	-----
Camps	CA																									
Pond	VMT	.21																								
Sawmill	VMT	2.61 } 3.16	5.23	4.55	4.12	3.81	3.59	3.41	3.26	3.13	3.02	2.90	2.82	2.73	2.64	2.57	2.51	2.44	2.37	2.31	2.24	-----	-----	-----	-----	-----
Green chain	VMT	.34																								
Yards and kilns	V no. pcs.	2.25 } 3.76	5.91	5.59	4.80	4.47	4.22	4.03	3.88	3.73	3.59	3.46	3.35	3.26	3.19	3.13	3.08	3.04	3.02	2.99	2.99	-----	-----	-----	-----	-----
Shipping	V no. pcs.	1.51																								
Planing mills	C	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	-----	-----	-----	-----	-----
Selling	C	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	-----	-----	-----	-----	-----
Depreciation on sawmill and planing mill	VMT	1.22																								
Insurance on plant	VMT	.37																								
Taxes on plant and timber	VMT	.85 } 4.32	7.15	6.21	5.64	5.21	4.91	4.67	4.46	4.27	4.12	3.97	3.85	3.73	3.61	3.52	3.43	3.33	3.24	3.15	3.06	-----	-----	-----	-----	-----
General expense	VMT	1.88																								
Insurance on lumber	VP	.20																								
Taxes on lumber	VP	.09 } .72	.63	.64	.65	.66	.68	.68	.70	.71	.73	.74	.75	76	.78	.79	.80	.82	.83	.84	.85	-----	-----	-----	-----	-----
Discount on sales	VP	.43																								
Allowance and adjustments	C	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	-----	-----	-----	-----	-----
Total		20.72	33.01	28.86	26.24	24.57	23.32	22.19	21.25	20.46	19.79	19.16	18.67	18.22	17.81	17.49	17.20	16.94	16.68	16.45	16.29	-----	-----	-----	-----	-----

[1] Excluding stumpage, Federal taxes, and interest.

[2] Code for classification of costs: C=constant per thousand board feet; CA=constant per acre; V Cap=varies with the capacity of the cars when they are loaded with logs of 1 size only; VMT=varies with the time in the mill; V no. pcs.=varies with the number of pieces needed to make up 1,000 board feet; VP=varies with the price; VT=varies with the time per 1,000 board feet required for lumber of different sizes; V Tot= varies with the sum of the other logging costs, excluding CA costs.

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SECOND-GROWTH OLD-FIELD LOBLOLLY PINE TREES, NORTHERN LOUISIANA

Sawing; labor, scaling, and expense	VT		0.72	2.27	1.61	1.25	1.07	0.96	0.87	0.79	0.71	0.65	0.60	0.58	0.56	0.55	0.54	0.55	0.55	0.56	0.57	0.58	-----	-----	-----	-----	-----
Hauling; labor, scaling, and expense	VT		2.27	4.02	3.97	3.85	3.58	3.18	2.81	2.52	2.28	2.09	1.92	1.81	1.72	1.67	1.62	1.59	1.58	1.56	1.56	1.56	-----	-----	-----	-----	-----
Loading:																											
Labor	VT	0.42	.51	2.05	1.69	1.41	1.13	.90	.71	.59	.49	.42	.37	.33	.30	.27	.25	.23	.21	.20	.18	.17	-----	-----	-----	-----	-----
Expense	VT	.09																									
Spur tracks; labor and expense	CA		1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	-----	-----	-----	-----	-----
Railroad transportation:																											
Railroad labor	V Cap	.45	1.42	1.79	1.85	1.86	1.81	1.70	1.59	1.51	1.44	1.38	1.34	1.30	1.26	1.24	1.22	1.19	1.16	1.13	1.09	1.06	-----	-----	-----	-----	-----
Railroad expense	V Cap	.97																									
Railroad maintenance	VMT		.23	.46	.42	.37	.33	.30	.26	.24	.23	.21	.21	.20	.20	.19	.19	.19	.19	.19	.18	.18	-----	-----	-----	-----	-----
Woods supervision	V Tot		.22	.46	.41	.38	.34	.30	.27	.24	.23	.21	.19	.19	.18	.17	.17	.16	.16	.16	.16	.15	-----	-----	-----	-----	-----
Sawmill and pond:																											
Labor	VMT	2.52	3.85	7.75	6.95	6.23	5.55	4.95	4.41	4.00	3.77	3.59	3.45	3.36	3.30	3.25	3.20	3.16	3.14	3.11	3.09	3.07	-----	-----	-----	-----	-----
Expense	VMT	1.33																									
Kilns and yard:																											
Yard and sorter labor	V no. pcs.	.92	1.96	2.93	2.79	2.63	2.50	2.33	2.18	2.06	1.96	1.90	1.82	1.79	1.74	1.71	1.69	1.67	1.65	1.63	1.62	1.61	-----	-----	-----	-----	-----
Yard expense	V no. pcs.	.30																									
Dry-kiln and shed labor	V no. pcs.	.69																									
Dry-kiln expense	V no. pcs.	.05																									
Planer labor and expense	C	.94	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	-----	-----	-----	-----	-----
Selling expense	C	.72																									
Shipping labor and expense	V no. pcs.		1.78	2.66	2.53	2.39	2.27	2.12	1.98	1.87	1.78	1.73	1.66	1.62	1.58	1.56	1.53	1.51	1.50	1.48	1.47	1.46	-----	-----	-----	-----	-----
Miscellaneous allowance; claims and corrections	C		.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	.82	-----	-----	-----	-----	-----
Administration expense:																											
General expense	VMT	.98	6.03	12.14	10.89	9.75	8.69	7.76	6.91	6.27	5.91	5.62	5.41	5.27	5.16	5.09	5.02	4.95	4.91	4.88	4.84	4.81	-----	-----	-----	-----	-----
Office expense	VMT	.44																									
Legal expense	VMT	.05																									
Accident insurance	VMT	.33																									
Insurance on plant and equipment	VMT	.46																									
Taxes on land and plant	VMT	.85																									
Land and timber expense	VMT	.20																									
Loyalty and service	VMT	.34																									
Depreciation	VMT	2.03																									
Machine-shop labor and expense	VMT	.35																									
Insurance on lumber	VP	.15	.73	.71	.71	.71	.71	.70	.71	.71	.72	.73	.73	.74	.75	.76	.77	.78	.78	.79	.79	.80	-----	-----	-----	-----	-----
Taxes on lumber	VP	.18																									
Discount on lumber	VP	.40																									
Total	----------		23.49	41.01	37.59	34.60	31.75	28.97	26.47	24.57	23.29	22.30	21.47	20.96	20.52	20.23	19.97	19.75	19.60	19.46	19.32	19.22	-----	-----	-----	-----	-----

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TABLE 7.—*Production costs per thousand board feet, lumber tally, by diameter classes for the four operations studied*—Continued

VIRGIN-GROWTH FLATLAND SHORTLEAF PINE TREES, EASTERN TEXAS

Cost item	Classification of cost	Weighted average cost per thousand board feet, lumber tally	Itemized costs for the indicated diameter breast high in inches																							
			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Sawing:																										
Labor	VT	0.87																								
Material and supplies	VT	.01	0.88	-----	-----	1.03	1.00	0.97	0.95	0.93	0.91	0.90	0.88	0.87	0.85	0.85	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Skidway and teamsters:																										
Labor	VT	.69																								
Material and supplies	VT	.18	1.49	-----	-----	3.11	2.77	2.45	2.18	1.97	1.79	1.63	1.51	1.39	1.28	1.21	1.15	1.09	1.04	1.02	.99	.97	.95	.94	.92	.92	.92
Feed	VT	.62																								
Loading:																										
Labor	VT	.34																								
Material and supplies	VT	.10	.44	-----	-----	1.13	.99	.83	.71	.62	.54	.49	.44	.40	.36	.33	.31	.29	.27	.26	.25	.23	.23	.22	.21	.20	.20
Railroad transportation:																										
Woods engine:																										
Labor	V Cap	.44																								
Material and supplies	V Cap	.36	2.61	-----	-----	3.94	3.67	3.45	3.24	3.05	2.88	2.71	2.61	2.48	2.41	2.33	2.30	2.26	2.25	2.23	2.22	2.20	2.17	2.15	2.12	2.10	2.07
Main logging road	V Cap	1.81																								
Spur track:																										
Labor	CA	1.04																								
Material and supplies	CA	.11	1.15	-----	-----	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Miscellaneous logging expenses	V Tot	.41	-----	-----	.70	.64	.58	.53	.50	.46	.43	.41	.39	.37	.35	.35	.34	.34	.33	.32	.32	.32	.31	.31	.31	.30
Pond:																										
Labor	VT	.21																								
Material and supplies	VT	.03																								
Sawmill:																										
Labor	VT	1.68																								
Material and supplies	VT	.27	2.44	-----	-----	2.81	2.77	2.73	2.68	2.64	2.60	2.55	2.51	2.47	2.42	2.38	2.34	2.29	2.25	2.21	2.17	2.12	2.08	2.04	1.99	1.95	1.91
Oil	VT	.04																								
Green chain:																										
Labor	VT	.19																								
Material and supplies	VT	.02																								

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Stacking and loading kilns	V no. pcs.	.42																									
Dry kiln:																											
Labor	V no. pcs.	.25																									
Material and supplies	V no. pcs.	.12																									
Rough shed																											
Labor	V no. pcs.	.47	1.72	-----	-----	2.05	1.98	1.91	1.85	1.80	1.76	1.74	1.72	1.70	1.69	1.68	1.67	1.66	1.65	1.64	1.63	1.63	1.62	1.61	1.60	1.60	1.59
Material and supplies	V no. pcs.	.05																									
Yard:																											
Labor	V no. pcs.	.26																									
Material and supplies	V no. pcs.	.14																									
Timber-dock labor and material and supplies	V no. pcs.	.01																									
Planer and shipping:																											
Hauling	C	.34																									
Planing:																											
Labor	C	.70																									
Material and supplies and oil	C	.17	3.41	-----	-----	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
Shipping labor and material and supplies	C	.69																									
Finish-shed labor and material and supplies	C	.01																									
Selling	C	1.50																									
General expenses:																											
Office and office salary	VMT	.50																									
Office expense	VMT	.06																									
Taxes on plant and timber	VMT	1.15																									
Insurance on plant and timber	VMT	.22	4.27	-----	-----	4.93	4.85	4.77	4.70	4.62	4.55	4.47	4.39	4.32	4.24	4.17	4.09	4.02	3.94	3.86	3.79	3.71	3.64	3.56	3.49	3.41	3.33
Accident insurance	VMT	.26																									
Depreciation	VMT	1.80																									
General and dwelling-house, labor material, and supplies	VMT	.28																									
Insurance on lumber	VP	.11																									
Taxes on lumber	VP	.06	.34	-----	-----	.29	.30	.30	.31	.31	.32	.32	.33	.33	.34	.35	.35	.36	.37	.37	.38	.39	.39	.40	.40	.41	.41
Discounts	VP	.17																									
Total			19.16	-----	-----	24.55	23.53	22.55	21.71	21.00	20.37	19.80	19.36	18.91	18.52	18.21	17.96	17.71	17.51	17.32	17.15	16.97	16.80	16.63	16.44	16.30	16.13

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TABLE 7.—*Production costs per thousand board feet, lumber tally, by diameter classes for the four operations studied*—Continued

VIRGIN-GROWTH MOUNTAIN SHORTLEAF PINE TREES, WEST-CENTRAL ARKANSAS

Cost item	Classification of cost	Weighted average cost per thousand board feet, lumber tally	Itemized costs for the indicated diameter breast high in inches																							
			8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Sawing:																										
Labor	VT	0.83																								
Tools and supplies	VT	.01 } 0.98	-----	2.48	2.20	1.94	1.69	1.47	1.29	1.14	1.04	0.95	0.89	0.85	0.82	0.80	0.79	0.79	0.81	0.81	0.84	0.86	0.89	0.90	-----	-----
Scaling and supervision.	VT	.14																								
Brush disposal	VT	.37	-----	1.25	1.05	.86	.71	.59	.51	.45	.40	.36	.33	.32	.29	.28	.28	.26	.26	.26	.26	.26	.26	.26	-----	-----
Skidding, wagon haul, and swamping	VT	2.78																								
Scaling	VT	.06 } 2.84	-----	8.28	7.13	6.19	5.36	4.62	4.00	3.49	3.11	2.81	2.58	2.40	2.24	2.12	2.03	1.98	1.95	1.95	1.97	2.01	2.08	2.15	-----	-----
Loading on cars	VT	1.09	-----	3.89	3.36	2.87	2.42	2.04	1.73	1.48	1.29	1.14	1.00	.87	.77	.67	.61	.55	.51	.47	.45	.44	.44	.44	-----	-----
Spur tracks	CA	1.49	-----	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	-----	-----
Main-line maintenance, train labor, and supplies	VMT	.92	-----	1.37	1.31	1.26	1.21	1.16	1.10	1.06	1.01	.96	.92	.87	.83	.79	.76	.73	.71	.70	.69	.69	.71	.72	-----	-----
Freight	V Cap	1.24	-----	2.06	1.90	1.76	1.62	1.51	1.41	1.35	1.29	1.24	1.20	1.17	1.15	1.13	1.12	1.12	1.12	1.14	1.15	1.18	1.20	1.23	-----	-----
Salaries	V Tot	.07																								
Office expense	V Tot	.01																								
Liability	V Tot	.12																								
Group insurance	V Tot	.01																								
Motor-car repairs and supplies	V Tot	.15 } 1.20	-----	3.12	2.74	2.40	2.10	1.84	1.62	1.45	1.31	1.21	1.12	1.05	.98	.93	.90	.87	.87	.86	.86	.88	.90	.92	-----	-----
Miscellaneous expense	V Tot	.17																								
Fire and locomotive insurinsurance	V Tot	.01																								
Taxes	V Tot	.06																								
Depreciation	V Tot	.60																								
Sawmill and pond:																										
Pond expense	VMT	.13																								
Sawmill labor	VMT	1.42																								
Sawmill repair and supplies	VMT	.38 } 2.28	-----	3.39	3.25	3.11	2.99	2.87	2.73	2.62	2.50	2.38	2.27	2.17	2.06	1.96	1.89	1.82	1.77	1.73	1.71	1.73	1.75	1.78	-----	-----
Power	VMT	.35																								

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Kilns, rip mill, and chains:																									
Green chain	VMT	.34																							
Green lumber transportation	VMT	.11																							
Power	VMT	.18	1.08	-----	1.61	1.54	1.47	1.42	1.36	1.29	1.24	1.18	1.13	1.08	1.03	.98	.93	.89	.86	.84	.82	.81	.82	.83	.84	-----	-----
Tram and shed repairs	VMT	.05																									
Rip-mill labor	VMT	.35																									
Rip-mill repairs and supplies	VMT	.07																									
Dry-kiln labor	V no. pcs.	.85																									
Dry-kiln repairs and supplies	V no. pcs.	.06	1.45	-----	2.28	2.13	1.99	1.87	1.76	1.68	1.61	1.54	1.48	1.43	1.37	1.33	1.28	1.26	1.25	1.24	1.25	1.26	1.27	1.29	1.31	-----	-----
Dry-lumber transportation	V no. pcs.	.15																									
Shed stacking and cleaning	V no. pcs.	.39																									
Planing mill:																											
Handling and trucking to planer	C	.42																									
Planer labor	C	.91	1.64	-----	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	-----	-----
Planer repairs and supplies	C	.14																									
Planer power	C	.17																									
Shipping expenses:																											
Labor	V no. pcs.	.62																									
Supplies and repairs	V no. pcs.	.12	.78	-----	1.22	1.15	1.07	1.00	.95	.90	.86	.83	.80	.77	.74	.71	.69	.68	.67	.67	.67	.68	.68	.69	.70	-----	-----
Wrapped-trim labor and supplies	V no. pcs.	.04																									
General expense:																											
Salaries	VMT	.56																									
Office expense	VMT	.05																									
Liability insurance	VMT	.18																									
Group life insurance	VMT	.09																									
Fire insurance on plant	VMT	.51																									
Fire protection and watchman	VMT	.07	3.61	-----	5.37	5.15	4.93	4.73	4.54	4.32	4.15	3.96	3.77	3.60	3.43	3.27	3.10	2.99	2.88	2.80	2.74	2.71	2.74	2.77	2.82	-----	-----
Waterworks	VMT	.02																									
Taxes on plant	VMT	.10																									
Depreciation	VMT	1.07																									
Miscellaneous expense	VMT	.42																									
Administration	VMT	.54																									
Selling expense	C		1.67	-----	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	-----	-----
Taxes on lumber	VP	.13																									
Insurance on lumber	VP	.14	.86	-----	.71	.70	.71	.72	.74	.76	.79	.81	.84	.86	.89	.91	.93	.94	.95	.96	.96	.97	.96	.96	.95	-----	-----
Discount	VP	.59																									
Total	-----		23.50	-----	41.83	38.41	35.36	32.64	30.25	28.14	26.49	25.07	23.87	22.85	21.96	21.14	20.41	19.94	19.53	19.31	19.16	19.16	19.32	19.57	19.82	-----	-----

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For all the steps in lumber manufacture that vary with time, the unit production costs are much greater for small trees than for large ones. This holds true throughout; the different degrees of efficiency in the same steps or in different steps of logging and milling do not change the essential fact that it costs considerably more to handle small trees than to handle large ones.

LUMBER PRICES

For the purpose of computing the sales value of lumber produced from trees of different sizes, prices have been determined from the company's records for each grade of lumber and for different widths in each grade. These figures, which represent the average sales value of the lumber f.o.b. shipping point during 1929, are shown in table 8. In the same table are also the prices that represent the value of 1,000 feet of green lumber, board measure, when dry and dressed. The figures can be applied to the green-chain grade and piece tally to obtain the sales value of the lumber when dry and finished.

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TABLE 8.—*Average prices per thousand feet, board measure, for dressed*[1] *lumber f.o.b. mill for the 4 operations studied, 1929*

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE, SOUTHERN ARKANSAS

Item	Grade																												
	B and Better					No. 1 Common and C					No. 1 Common					No. 2 Common					No. 3 Common					Timber			
	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	10 to 16 feet long	18 to 20 feet long	22 to 24 feet long	All lengths
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Boards, 4/4-inch, dry and dressed:																													
Including edge grain	44.25	49.00	60.75	68.00	68.50	35.00	35.25	35.75	42.50	55.25	----	----	----	----	----	19.50	21.75	22.75	22.75	24.75	14.25	16.50	18.50	19.00	19.75	----	----	----	----
Excluding edge grain	40.65	----	----	----	----	34.25	----	----	----	----	----	----	----	----	----	18.15	----	----	----	----	----	----	----	----	----	----	----	----	----
Green stock after drying, remanufacture, and dressing:																													
Including edge grain	41.37	46.84	54.86	63.31	64.18	31.82	34.47	33.60	38.08	44.86	----	----	----	----	----	18.90	20.42	22.02	22.23	24.40	14.08	16.30	18.28	18.77	19.51	----	----	----	----
Excluding edge grain	38.54	----	----	----	----	31.17	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Dimension, 8/4-inch	----	----	----	----	----	----	----	----	----	----	26.25	24.25	27.25	28.00	30.00	23.75	21.75	22.75	21.50	26.75	16.75	17.00	----	----	----	----	----	----	----

SECOND-GROWTH OLD-FIELD LOBLOLLY PINE, NORTHERN LOUISIANA

Boards, 4/4-inch:																													
Dry and dressed	37.63	40.47	43.35	52.14	54.18	30.79	34.95	33.25	38.58	49.84	----	----	----	----	----	19.52	20.11	22.85	23.36	26.88	15.82	15.82	16.49	18.62	18.80	----	----	----	----
Green stock after drying, remanufacture, and dressing	36.80	39.58	42.40	50.99	52.99	30.11	34.18	32.52	37.73	48.74	----	----	----	----	----	19.25	19.77	22.42	22.92	26.18	15.82	15.82	16.49	18.62	18.80	----	----	----	----
Dimension, 8/4-inch:																													
Dry and dressed	----	----	----	----	----	----	----	----	----	----	30.16	29.30	29.84	32.24	39.62	24.39	21.26	25.07	24.52	28.71	17.00	17.00	17.00	17.00	17.00	----	----	----	----
Green stock after drying, remanufacture, and dressing	----	----	----	----	----	----	----	----	----	----	30.04	29.18	29.72	32.11	39.46	24.29	21.17	24.97	24.42	28.60	17.00	17.00	17.00	17.00	17.00	----	----	----	----

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TABLE 8.—*Average prices per thousand feet, board measure, for dressed lumber f.o.b. mill for the 4 operations studied, 1929*—Continued

VIRGIN-GROWTH FLATLAND SHORTLEAF PINE, EASTERN TEXAS

Item	Grade																												
	B and Better					No. 1 Common and C					No. 1 Common					No. 2 Common					No. 3 Common					Timber			
	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	4 inches wide	6 inches wide	8 inches wide	10 inches wide	12 inches wide	10 to 16 feet long	18 to 20 feet long	22 to 24 feet long	All lengths
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
All lumber, dry and dressed	49.25	50.80	51.40	51.60	67.75	34.60	38.02	35.17	42.00	52.12						20.75	21.71	24.36	25.18	27.60	16.75	18.00	19.00	20.00	20.12				
Green stock after drying, remanufacture, and dressing:																													
Boards, 4/4-inch	45.06	46.68	46.95	52.60	62.32	32.18	35.08	32.83	38.66	47.27						20.72	21.68	24.14	24.70	27.34	16.67	17.92	18.91	19.90	20.02				
Dimension, 8/4 inch																26.10	26.10	26.10	26.10	26.10	14.95	14.95	14.95	14.95	14.95				
Length, 10 feet											30.75	25.00	30.75	31.75	37.00														
Length, 12 feet											28.50	25.00	28.50	30.75	37.75														
Length, 14 feet											28.50	25.00	28.25	30.25	35.50														
Length, 16 feet											29.00	25.38	28.50	31.50	33.25														
Length, 18 feet											32.00	27.00	31.75	32.25	37.25														
Length, 20 feet											32.00	27.50	31.75	32.25	37.75														
Length, 22 and 24 feet											35.50	35.50	35.50	37.50	44.50														
Size (inches):																													
3 by 4, 3 by 6, 3 by 8, 4 by 4																										28.25	30.25	33.25	
4 by 6, 4 by 8, 6 by 6, 8 by 8																										26.75	28.75	31.75	
3 by 10, 4 by 10																										31.75	33.75	36.75	
3 by 12, 4 by 12																										37.75	39.75	42.75	
12 by 12																										34.75	36.75	39.75	

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VIRGIN-GROWTH MOUNTAIN SHORTLEAF PINE, WEST-CENTRAL ARKANSAS

Boards 4/4 inch:																													
Dry and dressed	45.85	49.70	60.75	67.50	68.50	35.75	39.15	35.00	41.80	53.65	----	----	----	----	----	20.10	20.40	23.40	23.80	29.85	16.60	17.60	18.80	18.90	20.40	----	----	----	----
Green stock after drying, remanufacture, and dressing	44.78	48.15	58.01	63.11	58.73	35.56	37.40	34.02	40.19	47.08	----	----	----	----	----	20.67	22.20	23.43	24.02	29.50	15.77	16.70	17.47	18.10	19.10	----	----	----	----
Dimension, 8/4-inch																													
Dry and dressed	----	----	----	----	----	----	----	----	----	----	29.80	25.60	28.20	31.50	36.00	25.50	20.00	23.50	23.70	25.25	----	----	----	----	----	----	----	----	----
Green stock after drying, remanufacture, and dressing	----	----	----	----	----	----	----	----	----	----	29.44	24.80	28.02	31.21	35.65	24.75	19.40	23.50	23.70	25.25	----	----	----	----	----	----	----	----	----
All sizes	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	28.25

[1] The sales value of 1,000 board feet of green lumber when dry and dressed was obtained from the price of dry and dressed lumber by deducting enough to cover the kiln and planer degrade.

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LUMBER GRADES

As long as clear lumber commands a premium, the timberland manager should concern himself with the quality increment as well as the quantity increment of the stand. The average sawmill operator, when he includes stumpage in the costs, makes money from the no. 1 common and better lumber he cuts out of the log and just about comes out even or perhaps loses money on the rest. The comparative amount of high-grade lumber in a tree is therefore extremely important to lumbermen, and information on grades and sales value is necessary in working out management plans and computing economic cutting limits. Table 9 gives information on the grades of lumber obtained from trees of different sizes that were cut for this study. As previously explained these figures are the direct result of adding up the lumber tally for the logs that came from the trees.

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TABLE 9.—*Percentage of the total mill output and sales value per thousand board feet, lumber tally, of the various grades sawed from trees of different diameters in the four operations studied*

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE IN SOUTHERN ARKANSAS

Diameter breast high	Grade in green condition																Average value per thousand board feet of green lumber when dry and dressed
	Boards								Dimension						Timbers		
	B and better		No. 1 common and C		No. 2 common		No. 3 common		No. 1 common		No. 2 common		No. 3 common				
	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	
	Percent	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Dollars*
8 inches	0.9	42.00	3.0	32.60	38.2	19.00	10.3	14.10	30.6	26.00	12.0	23.00	5.0	16.75			21.62
9 inches	1.1	42.20	5.0	32.80	41.4	19.40	8.9	14.40	28.9	26.00	10.5	23.00	4.2	16.75			22.05
10 inches	1.7	42.50	6.8	32.90	44.3	19.80	8.0	14.80	26.7	26.00	9.1	23.00	3.4	16.75			22.52
11 inches	2.5	43.00	8.4	33.10	47.7	20.10	7.4	15.30	23.6	26.00	7.8	23.00	2.6	16.75			22.94
12 inches	3.6	43.60	9.8	33.30	52.3	20.40	6.9	15.90	19.0	26.00	6.5	23.00	1.9	16.75			23.35
13 inches	5.0	44.40	10.8	33.40	61.2	20.80	6.6	16.40	9.8	26.00	5.3	23.00	1.3	16.75			23.62
14 inches	6.5	45.20	11.5	33.50	65.3	21.10	6.5	16.80	5.4	26.00	4.0	23.00	.8	16.75			24.12
15 inches	8.2	46.00	11.8	33.70	67.3	21.30	6.4	17.10	2.9	26.00	3.0	23.00	.4	16.75			24.69
16 inches	9.7	46.90	11.4	34.00	68.8	21.50	6.4	17.30	1.6	26.00	2.0	23.00	.1	16.75			25.22
17 inches	11.0	47.80	10.2	34.30	69.7	21.70	6.6	17.40	1.1	26.00	1.4	23.00		16.75			25.64
18 inches	12.2	48.70	9.0	34.80	70.0	21.90	7.1	17.50	.8	26.00	.9	23.00		16.75			26.06
19 inches	13.2	49.60	8.2	35.50	69.6	22.00	8.0	17.60	.4	26.00	.6	23.00		16.75			26.42
20 inches	14.2	50.50	7.6	36.30	68.6	22.20	9.1	17.70	.2	26.00	.3	23.00		16.75			26.89
21 idches	15.1	51.40	7.1	37.20	67.3	22.40	10.5	17.80		26.00		23.00		16.75			27.35
22 inches	15.9	52.30	6.7	38.20	65.2	22.60	12.2	17.90		26.00		23.00		16.75			27.79
23 inches	16.7	53.20	6.4	39.30	62.7	22.80	14.2	17.90		26.00		23.00		16.75			28.24
24 inches	17.5	54.20	6.2	40.40	59.9	22.90	16.4	18.00		26.00		23.00		16.75			28.66
25 inches	18.3	55.10	6.0	41.50	56.9	23.10	18.8	18.00		26.00		23.00		16.75			29.10
26 inches	19.0	56.00	5.8	42.60	53.8	23.20	21.4	18.00		26.00		23.00		16.75			29.44
Weighted average	8.5	47.91	9.8	34.15	63.5	21.37	7.4	16.90	6.7	26.00	3.3	23.00	.8	16.75			24.88

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TABLE 9.—*Percentage of the total mill output and sales value per thousand board feet, lumber tally, of the various grades sawed from trees of different diameters in the four operations studied*—Continued

VIRGIN-GROWN FLATLAND SHORTLEAF PINE IN EASTERN TEXAS

Diameter breast high	Grade in green condition																Average value per thousand board feet of green lumber when dry and dressed
	Boards								Dimension						Timbers		
	B and better		No. 1 common and C		No. 2 common		No. 3 common		No. 1 common		No. 2 common		No. 3 common				
	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	Amount	Value	
	Percent	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Dollars*
10 inches	2.6	44.35	6.1	33.50	19.0	21.20	7.7	17.65	20.4	28.10	5.2	26.10	1.0	14.95	38.0	28.00	26.46
11 inches	3.4	44.70	6.6	33.55	20.2	21.35	6.4	17.80	26.0	28.30	6.0	26.10	1.0	14.95	30.4	28.05	26.79
12 inches	4.3	45.05	7.1	33.65	21.4	21.55	4.1	17.90	29.1	28.80	6.6	26.10	1.0	14.95	26.4	28.10	27.34
13 inches	5.3	45.45	7.7	33.80	22.6	21.80	2.9	18.05	30.0	29.20	7.0	26.10	1.0	14.95	23.5	28.25	27.84
14 inches	6.5	45.90	8.2	33.90	23.6	22.10	2.4	18.15	29.7	29.65	7.2	26.10	1.0	14.95	21.4	28.45	28.34
15 inches	8.0	46.40	8.7	34.00	24.4	22.35	3.2	18.30	27.7	30.10	7.2	26.10	1.0	14.95	19.8	28.70	28.76
16 inches	9.7	46.80	9.2	34.10	25.6	22.70	5.1	18.45	23.8	30.55	7.0	26.10	1.0	14.95	18.6	29.00	29.07
17 inches	11.5	47.20	9.7	34.25	26.2	23.00	6.2	18.55	21.1	30.95	6.7	26.10	1.1	14.95	17.5	29.35	29.51
18 inches	13.3	47.55	10.2	34.45	25.7	23.30	7.6	18.70	19.2	31.40	6.3	26.10	1.1	14.95	16.6	29.75	30.02
19 inches	15.1	47.90	10.6	34.70	25.6	23.65	8.2	18.80	17.8	31.80	5.8	26.10	1.1	14.95	15.8	30.15	30.61
20 inches	16.9	48.20	11.1	35.00	25.2	23.95	8.7	18.90	16.7	32.15	5.2	26.10	1.2	14.95	15.0	30.60	31.21
21 inches	18.6	48.55	11.5	35.35	24.6	24.25	9.1	19.05	15.8	32.55	4.8	26.10	1.2	14.95	14.4	31.10	31.85
22 inches	20.3	48.85	12.0	35.75	23.6	24.50	9.6	19.20	15.1	32.90	4.4	26.10	1.2	14.95	13.8	31.65	32.50
23 inches	21.8	49.20	12.4	36.15	22.4	24.75	10.2	19.30	14.6	33.30	4.2	26.10	1.2	14.95	13.2	32.20	33.11
24 inches	23.3	49.45	12.9	36.60	21.1	25.00	10.7	19.40	14.2	33.60	4.0	26.10	1.2	14.95	12.6	32.80	33.72
25 inches	24.6	49.70	13.3	37.10	19.8	25.20	11.3	19.50	13.9	33.85	3.8	26.10	1.1	14.95	12.2	33.50	34.30
26 inches	25.8	49.95	13.7	37.55	18.6	25.35	11.8	19.60	13.7	34.10	3.6	26.10	1.0	14.95	11.8	34.05	34.84
27 inches	26.9	50.20	14.1	37.95	17.5	25.45	12.3	19.65	13.6	34.30	3.4	26.10	.9	14.95	11.3	34.70	35.33
28 inches	28.0	50.40	14.4	38.30	16.5	25.60	12.7	19.70	13.5	34.45	3.2	26.10	.8	14.95	10.9	35.30	35.81
29 inches	28.9	50.60	14.6	38.70	15.8	25.70	13.0	19.75	13.4	34.60	3.0	26.10	.7	14.95	10.6	35.95	36.24
30 inches	29.6	50.75	14.7	39.00	15.2	25.80	13.2	19.80	13.4	34.65	2.8	26.10	.7	14.95	10.4	36.50	36.56
31 inches	30.3	50.85	14.8	39.25	14.7	25.90	13.3	19.85	13.4	34.70	2.6	26.10	.7	14.95	10.2	37.00	36.87
Weighted average	14.3	48.39	10.4	35.28	23.4	23.35	7.1	18.97	20.8	31.02	5.7	26.10	1.1	14.95	17.2	29.92	30.65

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VIRGIN-GROWTH MOUNTAIN SHORTLEAF PINE IN WEST-CENTRAL ARKANSAS

9 inches	3.0	44.80	11.2	35.55	44.2	21.20	5.5	16.30	26.8	29.40	6.8	24.75	2.5	14.75	--------	--------	25.52
10 inches	4.4	45.40	11.3	36.30	44.9	21.55	5.8	16.45	24.2	26.20	6.7	23.85	2.7	14.95	--------	--------	25.07
11 inches	6.0	46.15	11.5	36.55	45.2	21.85	6.2	16.60	21.6	25.90	6.7	22.00	2.8	15.05	--------	--------	25.37
12 inches	7.8	47.35	11.6	36.35	45.3	22.15	6.5	16.70	19.1	26.05	6.6	20.90	2.8	15.05	0.3	28.25	25.89
13 inches	9.6	48.65	11.8	35.75	44.9	22.40	6.9	16.80	16.8	26.55	6.6	21.35	2.8	14.90	.6	28.25	26.56
14 inches	11.4	49.85	11.9	35.45	44.3	22.65	7.3	16.90	14.9	27.20	6.6	21.85	2.8	14.80	.8	28.25	27.30
15 inches	13.2	51.10	12.0	35.75	43.6	22.80	7.7	17.00	13.3	28.05	6.5	22.20	2.7	15.20	1.0	28.25	28.15
16 inches	14.9	52.15	12.0	36.55	42.9	22.95	8.1	17.10	11.9	28.95	6.4	22.50	2.6	15.55	1.2	28.25	29.02
17 inches	16.5	53.20	12.0	37.40	41.9	23.20	8.6	17.20	10.8	29.80	6.3	22.80	2.6	15.70	1.3	28.25	29.90
18 inches	18.0	54.20	12.0	38.20	40.9	23.60	9.0	17.30	10.0	30.60	6.2	23.10	2.6	15.80	1.3	28.25	30.82
19 inches	19.4	55.05	12.0	38.95	40.1	24.05	9.6	17.40	9.2	31.35	6.0	23.35	2.5	15.90	1.2	28.25	31.69
20 inches	20.6	55.65	12.0	39.65	39.5	24.65	10.2	17.55	8.6	32.00	5.8	23.60	2.4	15.95	.9	28.25	32.51
21 inches	21.5	56.20	12.0	40.30	39.0	25.25	10.8	17.70	8.2	32.65	5.5	23.80	2.4	16.00	.6	28.25	33.22
22 inches	22.2	56.60	12.1	40.85	38.3	25.75	11.6	17.85	7.9	33.15	5.2	24.05	2.3	16.00	.4	28.25	33.79
23 inches	22.7	56.75	12.1	41.30	37.7	26.20	12.5	17.95	7.6	33.60	4.9	24.30	2.3	16.00	.2	28.25	34.17
24 inches	23.1	56.70	12.1	41.70	37.1	26.55	13.6	18.05	7.4	33.85	4.5	24.50	2.2	16.00	--------	28.25	34.41
25 inches	23.4	56.55	12.2	41.85	36.4	26.80	14.6	18.15	7.2	33.95	4.0	24.70	2.2	16.00	--------	--------	34.53
26 inches	23.7	56.40	12.2	41.90	35.8	26.95	15.7	18.20	7.0	34.10	3.5	24.90	2.1	16.00	--------	--------	34.58
27 inches	23.9	56.20	12.2	41.80	35.1	26.95	16.8	18.20	6.9	34.20	3.0	25.10	2.1	16.00	--------	--------	34.50
28 inches	24.1	55.95	12.2	41.50	34.4	26.75	18.0	18.20	6.8	34.25	2.5	25.30	2.0	16.00	--------	--------	34.31
29 inches	24.3	55.70	12.2	41.20	33.7	26.40	19.2	18.20	6.7	34.30	1.9	25.50	2.0	16.00	--------	--------	34.06
Weighted average	17.5	54.38	12.0	38.39	41.0	23.92	9.5	17.44	10.7	29.88	5.9	23.00	2.5	15.65	.9	28.25	30.79

SECOND-GROWTH OLD-FIELD LOBLOLLY PINE IN NORTHERN LOUISIANA

8 inches	0.4	36.80	5.6	30.10	39.6	19.25	6.6	15.60	23.5	30.05	17.8	24.30	6.5	17.00	--------	--------	22.98
9 inches	.6	36.80	6.2	30.10	41.1	19.25	6.5	15.60	23.2	30.05	17.6	24.30	4.8	17.00	--------	--------	23.80
10 inches	.8	36.80	6.5	30.45	43.2	19.30	6.4	15.60	22.4	29.85	17.3	24.05	3.4	17.00	--------	--------	23.03
11 inches	1.0	36.95	6.7	31.05	45.6	19.45	6.3	15.65	21.3	29.60	16.8	23.00	2.3	17.00	--------	--------	22.86
12 inches	1.2	37.20	6.8	31.75	48.5	19.70	6.2	15.70	19.4	29.45	16.3	22.45	1.6	17.00	--------	--------	22.78
13 inches	1.5	37.55	6.8	32.25	51.2	20.00	6.2	15.75	17.5	29.45	15.6	22.60	1.2	17.00	--------	--------	22.86
14 inches	1.7	37.90	6.7	32.65	53.4	20.35	6.3	15.85	16.1	29.55	14.9	22.80	.9	17.00	--------	--------	23.01
15 inches	2.1	38.30	6.5	32.95	54.9	20.70	6.7	16.00	15.0	29.70	14.1	23.15	.7	17.00	--------	--------	23.22
16 inches	2.4	38.70	6.3	33.20	56.2	21.10	7.2	16.15	14.0	30.00	13.3	23.50	.6	17.00	--------	--------	23.47
17 inches	2.7	39.20	6.0	33.40	57.2	21.45	8.0	16.40	13.0	30.40	12.6	23.80	.5	17.00	--------	--------	23.68
18 inches	3.1	39.65	5.7	33.60	57.9	21.80	8.9	16.75	11.9	31.10	12.0	24.20	.5	17.00	--------	--------	23.95
19 inches	3.5	40.20	5.4	33.85	58.5	22.20	10.0	17.00	10.9	32.30	11.3	24.60	.4	17.00	--------	--------	24.29
20 inches	3.9	40.80	5.0	34.05	58.9	22.55	11.2	17.20	9.9	34.20	10.7	25.00	.4	17.00	--------	--------	24.63
21 inches	4.3	41.60	4.7	34.25	59.1	22.90	12.5	17.30	8.9	35.85	10.1	25.45	.4	17.00	--------	--------	24.92
22 inches	4.8	42.50	4.4	34.45	59.2	23.25	14.0	17.35	7.7	37.10	9.5	25.90	.4	17.00	--------	--------	25.13
23 inches	5.2	43.35	4.1	34.65	59.0	23.60	15.5	17.40	6.8	38.05	9.0	26.30	.4	17.00	--------	--------	25.32
24 inches	5.6	44.15	3.8	34.85	58.8	23.95	17.0	17.45	6.0	38.70	8.4	26.80	.4	17.00	--------	--------	25.49
25 inches	6.0	44.90	3.5	35.00	58.4	24.30	18.6	17.50	5.3	39.20	7.8	27.20	.4	17.00	--------	--------	25.63
26 inches	6.4	45.50	3.2	35.15	58.0	24.70	20.1	17.55	4.7	39.45	7.2	27.65	.4	17.00	--------	--------	25.80
Weighted average	2.5	39.81	6.1	32.95	54.8	21.22	8.2	16.48	14.2	30.52	13.4	23.54	.8	17.00	--------	--------	23.60

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PRODUCTION COST AND LUMBER VALUE COMPARED

With unit production costs and the sales value of the lumber for trees of different diameters available, it is possible to compare the two and thus determine the gross difference available for stumpage, Federal taxes, interest, and profit, and also to determine the smallest tree that will pay its way. In making these comparisons it has been assumed that the cost of woods improvements, such as camps and spur tracks, is the same per thousand board feet for each diameter class as for the stand as a whole.

Table 10 gives a comparison of the total unit production cost, excluding stumpage, Federal taxes, and interest, and the unit sales value of the lumber for pine trees of different diameters.

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TABLE 10.—*Difference between production cost [1] and sales value per thousand feet, board measure, of green lumber from trees of different diameters from the 4 operations studied*

Diameter breast high	Second-growth, forest-grown mixed shortleaf and loblolly pine in southern Arkansas				Second-growth old-field loblolly pine in northern Louisiana				Virgin-growth mountain shortleaf pine in west-central Arkansas				Virgin-growth flatland shortleaf pine in eastern Texas		
	Total production cost [1]	Sales value	Difference between cost [1] and value		Total production cost [1]	Sales value	Difference between cost [1] and value		Total production cost [1]	Sales value	Difference between cost [1] and value		Total production cost [1]	Sales value	Difference between cost [1] and value, gross profit
			Loss	Gross profit			Loss	Gross profit			Loss	Gross profit			
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
8 inches	33.01	21.62	11.39		41.01	22.98	18.03								
9 inches	28.86	22.05	6.81		37.59	23.08	14.51		41.83	25.52	16.31				
10 inches	26.24	22.52	3.72		34.60	23.03	11.57		38.41	25.07	13.34		24.55	26.46	1.91
11 inches	24.57	22.94	1.63		31.75	22.86	8.89		35.36	25.37	9.99		23.53	26.79	3.26
12 inches	23.32	23.35		0.03	28.97	22.78	6.19		32.64	25.89	6.75		22.55	27.34	4.79
13 inches	22.19	23.62		1.43	26.47	22.86	3.61		30.25	26.56	3.69		21.71	27.84	6.13
14 inches	21.25	24.12		2.87	24.57	23.01	1.56		28.14	27.30	.84		21.00	28.34	7.34
15 inches	20.46	24.69		4.23	23.29	23.22	.07		26.49	28.15		1.66	20.37	28.76	8.39
16 inches	19.79	25.22		5.43	22.30	23.47		1.17	25.07	29.02		3.95	19.80	29.07	9.27
17 inches	19.16	25.64		6.48	21.47	23.68		2.21	23.87	29.90		6.03	19.36	29.51	10.15
18 inches	18.67	26.06		7.39	20.96	23.95		2.99	22.85	30.82		7.97	18.91	30.02	11.11
19 inches	18.22	26.42		8.20	20.52	24.29		3.77	21.96	31.69		9.73	18.52	30.61	12.09
20 inches	17.81	26.89		9.08	20.23	24.63		4.40	21.14	32.51		11.37	18.21	31.21	13.00
21 inches	17.49	27.35		9.86	19.97	24.92		4.95	20.41	33.22		12.81	17.96	31.85	13.89
22 inches	17.20	27.79		10.59	19.75	25.13		5.38	19.94	33.79		13.85	17.71	32.50	14.79
23 inches	16.94	28.24		11.30	19.60	25.32		5.72	19.53	34.17		14.64	17.51	33.11	15.60
24 inches	16.68	28.66		11.98	19.46	25.49		6.03	19.31	34.41		15.10	17.32	33.72	16.40
25 inches	16.45	29.10		12.65	19.32	25.63		6.31	19.16	34.53		15.37	17.15	34.30	17.15
26 inches	16.29	29.44		13.15	19.22	25.80		6.58	19.16	34.58		15.42	16.97	34.84	17.87
27 inches									19.32	34.50		15.18	16.80	35.33	18.53
28 inches									19.57	34.31		14.74	16.63	35.81	19.18
29 inches									19.82	34.06		14.24	16.44	36.24	19.80
30 inches													16.30	36.56	20.26
31 inches													16.13	36.87	20.74
Weighted average	20.72	24.88		4.16	23.49	23.60		.11	23.49	30.79		7.30	19.16	30.65	11.49

[1] Excluding stumpage, Federal taxes, and interest.

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The question of what effect a decline in lumber prices has on cutting limits often arises. If declines of 10 percent in production cost and also in lumber value had occurred simultaneously, in this operation, no change in the size of the tree that was barely paying its way would have occurred, because production costs and sales value are nearly equal in the diameter classes among which the change from profit to loss comes. If sales value alone had declined 10 percent and the production costs had remained the same, then the minimum size of the trees that paid their ways in the southern Arkansas stand would have been 14 inches instead of 12. Or, if production costs had been reduced 10 percent and lumber prices had remained the same, a tree 11 inches in diameter would have paid its way, excluding stumpage, Federal taxes, and interest.

FINANCIAL RESULTS FOR DIFFERENT MINIMUM-DIAMETER CUTTING LIMITS

Cutting limits are discussed here primarily for the purpose of bringing out the economic aspects of selective logging applied to an entire stand. The controlling motive in marking a stand for sustained-yield management by selective logging should be to take out enough timber to justify logging and yet leave enough to reseed the land and also provide a return cut within a reasonable time. A minimum-diameter cutting limit may be used, but trees below this limit should be marked for cutting if they are defective, and healthy trees well above the minimum size may be left occasionally if they are needed for seeding purposes or to help out the next cut when the existing stand is heavy and yet is short of small trees. The financial returns under such conditions can be computed, once the volume distribution of the cut among the different diameter classes has been determined, just as easily as when a diameter limit is followed strictly, as is done in table 11.

TABLE 11.—*Gross return* [1] *per thousand board feet, lumber tally, and per acre in cutting to different minimum-diameter limits in the 4 operations studied*

SECOND-GROWTH, FOREST-GROWN MIXED SHORTLEAF AND LOBLOLLY PINE IN SOUTHERN ARKANSAS

Diameter breast high for cutting, inches	Volume removed per acre	Per thousand board feet, lumber tally			Gross profits [2] per acre
		Total production cost	Sales value	Difference: Gross profit [2]	
	Board feet, lumber tally	*Dollars*	*Dollars*	*Dollars*	*Dollars*
8 and up	12,636	20.72	24.88	4.16	52.57
9 and up	12,611	20.69	24.89	4.20	52.97
10 and up	12,371	20.56	24.94	4.38	54.18
11 and up	11,915	20.40	25.03	4.63	55.17
12 and up	11,247	20.23	25.16	4.93	55.45
13 and up	10,298	20.07	25.33	5.26	54.17
14 and up	8,958	19.96	25.58	5.62	50.34
15 and up	7,443	19.98	25.88	5.90	43.91
16 and up	5,926	20.21	26.18	5.97	35.38
17 and up	4,498	20.78	26.49	5.71	25.68
18 and up	3,274	21.90	26.81	4.91	16.08
19 and up	2,288	23.88	27.13	3.25	7.44
20 and up	1,530	27.35	27.48	.13	.20
21 and up	961				
22 and up	569				
23 and up	303				
24 and up	139				
25 and up	51				
26 and up	13				

[1] Excluding stumpage, Federal taxes, and interest. [2] Minus sign indicates a loss.

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TABLE 11.—*Gross return per thousand board feet, lumber tally, and per acre in cutting to different minimum-diameter limits in the 4 operations studied*—Con.

Diameter breast high for cutting, inches	Volume removed per acre	Per thousand board feet, lumber tally: Total production cost	Sales value	Difference: Gross profit	Gross profits per acre
	Board feet, lumber tally	*Dollars*	*Dollars*	*Dollars*	*Dollars*
SECOND-GROWTH OLD-FIELD LOBLOLLY PINE IN NORTHERN LOUISIANA					
8 and up	17, 259	25. 97	23. 32	−2. 65	−45. 74
9 and up	16, 560	25. 39	23. 33	−2. 06	−34. 11
10 and up	15, 858	24. 91	23. 34	−1. 57	−24. 90
11 and up	14, 830	24. 33	23. 36	−. 97	−14. 39
12 and up	13, 444	23. 69	23. 42	−. 27	−3. 63
13 and up	11, 566	23. 04	23. 52	. 48	5. 55
14 and up	10, 048	22. 72	23. 62	. 90	9. 04
15 and up	8, 166	22. 60	23. 76	1. 16	9. 47
16 and up	6, 165	22. 79	23. 94	1. 15	7. 09
17 and up	4, 227	23. 60	24. 15	. 55	2. 32
18 and up	2, 631	25. 68	24. 44	−1. 24	−3. 26
19 and up	1, 438	30. 66	24. 84	−5. 82	−8. 37
20 and up	920	37. 10	25. 15	−11. 95	−10. 99
VIRGIN-GROWTH FLATLAND SHORTLEAF PINE IN EASTERN TEXAS					
10 and up	14, 474	19. 16	30. 65	11. 49	166. 31
11 and up	14, 445	19. 15	30. 66	11. 51	166. 26
12 and up	14, 213	19. 10	30. 72	11. 62	165. 16
13 and up	13, 620	19. 00	30. 87	11. 87	161. 67
14 and up	12, 708	18. 89	31. 09	12. 20	155. 04
15 and up	11, 536	18. 79	31. 36	12. 57	145. 01
16 and up	10, 161	18. 73	31. 72	12. 99	131. 99
17 and up	8, 829	18. 75	32. 12	13. 37	118. 04
18 and up	7, 628	18. 83	32. 53	13. 70	104. 50
19 and up	6, 542	19. 00	32. 94	13. 94	91. 20
20 and up	5, 558	19. 29	33. 36	14. 07	78. 20
21 and up	4, 661	19. 72	33. 77	14. 05	65. 49
VIRGIN-GROWTH MOUNTAIN SHORTLEAF PINE[3] IN WEST-CENTRAL ARKANSAS					
8 and up	6, 209	----------	----------	----------	----------
9 and up	6, 121	23. 55	29. 64	6. 09	37. 28
10 and up	6, 080	23. 44	29. 66	6. 22	37. 82
11 and up	6, 008	23. 27	29. 72	6. 45	38. 75
12 and up	5, 878	23. 04	29. 81	6. 77	39. 79
13 and up	5, 660	22. 72	29. 96	7. 24	40. 98
14 and up	5, 324	22. 34	30. 18	7. 84	41. 74
15 and up	4, 912	21. 98	30. 42	8. 44	41. 46
16 and up	4, 427	21. 66	30. 67	9. 01	39. 89
17 and up	3, 846	21. 36	30. 92	9. 56	36. 77
18 and up	3, 155	21. 15	31. 14	9. 99	31. 52
19 and up	2, 538	21. 09	31. 22	10. 13	25. 71
20 and up	2, 037	21. 24	31. 10	9. 86	20. 08
21 and up	1, 551	21. 74	30. 66	8. 92	13. 83
22 and up	1, 075	22. 99	29. 53	6. 54	7. 03

[3] Includes a volume of 286 board feet per acre, lumber tally, of red and white oak.

Of course there is no maximum-diameter cutting limit; all trees from the largest down to the minimum-diameter limit are removed, except only those left for seed and similar purposes. Hence a minimum-diameter cutting limit of 12 inches, for example, means that essentially all trees 12 inches and larger in diameter breast-high are to be cut.

Table 11 gives the weighted production cost, excluding stumpage, taxes, and interest; the value of the lumber; and the gross return per thousand board feet and also per acre under different minimum-

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diameter cutting limits. Before considering these results, however, it is desirable to understand clearly how leaving a part of the stand uncut affects the various factors in lumber production. In general, there are three classes of costs: (1) Varying expenditures, like those for felling and bucking, the amounts of which vary directly with the time required to cut 1,000 board feet of logs from trees of different sizes; (2) constant expenditures, such as those in the planing mill, that are constant per thousand board feet of lumber; and (3) completed or fixed expenditures, such as those for spur tracks, the apportionments of which vary with the amount of timber removal per acre. Unit-cost items in the first group decline in selective cutting as the smaller, more time-consuming trees are left to grow, whereas the apportionments of the permanent improvement costs increase as the amount of timber removed from each acre decreases.

APPLICATION OF RESULTS TO THE HANDLING OF TIMBERLANDS

Where the operator depends on natural reproduction to stock the land, as operators in southern yellow pine generally do, the manner of cutting the existing stand largely determines the degree to which the land will be kept productive, assuming of course that there is fire protection. Likewise, the method of cutting has a marked effect on both the immediate and the future profits of the operation, no matter whether the owner wants to make his operation permanent or to cut out and move on. Although selective cutting may not be perfectly satisfactory for all stands of southern yellow pine, it does have an extremely wide application. On very poor sites, however, selective cutting may not obtain the best results because reproduction in openings would have to meet too severe competition from the larger trees unless extremely heavy cutting and wide spacing are practiced. In fairly young and extremely thick stands, in whcih the tops are small, the trees left under selective cutting would probably not immediately show increased growth comparable with the extra amount of light and moisture that would be available. On the other hand, such a stand could probably be handled satisfactorily by harvesting this crop in two cuts, say 10 to 20 years apart. During the last cut enough thrifty small trees, carefully selected, might be left to develop in time a stand that could be handled by selective cutting.

COMPARISON OF SUSTAINED-YIELD AND PERIOD OPERATION

Any form of partial cutting, such as selective logging, has a bearing on the length of time that a mill can operate on the timber that a given tract will supply. This relation holds no matter whether the operator plans to cut clear and move on or, by some form of partial cutting, to extend the life of the operation or perhaps even make it permanent. In most period operations the depreciation and amortization charges for permanent improvements are high, even though the work is continued until every last stick of timber that will saw out a 2 by 4 has been taken The production cost is higher because small trees are included in the cut, and the average value of the lumber is reduced for the same reason. On the other hand, construction charges for camps and spur tracks are lower than those on partly cut areas with comparable stands. The increased cost for camps and spurs under selective cutting, however, is offset to a large degree by decreased costs for other items, such as felling and milling, which

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become less as the size of the timber increases. In fact, for the four different operations studied, 30 to 50 percent of the total volume of the stand could have been left uncut without having increased the unit production cost, because of the compensating effect of these factors. Meanwhile the average value of the lumber increases steadily as a larger percentage of the smaller trees are left uncut.

There are many things for an operator to consider before deciding to clear cut or to cut partly in an effort to develop a permanent or sustained-yield operation, but one question crowds all others into the background: Under which plan will he get the greater return in money? Almost any operating problem can be overcome when a certain way of doing a thing will yield a higher profit Definite figures for long-time operations to answer the question of how to cut are not abundant, but Hallauer (*5*) compares the results for southern yellow pine for a period and a sustained-yield operation and concludes that the sustained-yield is more profitable for virgin and second-growth shortleaf pine. His figures, especially the investments in plant and equipment, were drawn from actual operations, while some of the other costs were obtained from general figures that were checked by judgment.

In addition to the actual cash advantage of sustained-yield operation there are numerous others, some direct, and some the indirect ones that always result from permanency and stabilization in any community, such as better schools and roads and a satisfied class of labor. Any lumberman, therefore, who can see his way clear from a strictly financial standpoint, based solely on his profits from timber growing and lumber manufacture, to make his operation permanent by cropping his lands systematically is bound to reap additional benefits. He will reap them either directly, as for example through the operation of power plants and stores, or indirectly through the better social conditions that invariably obtain in a permanent community.

MINIMUM-DIAMETER LIMITS FOR SELECTIVE CUTTING

For the operator who is interested in only one cut there is a size of tree below which he should not go if he desires to make the most money per acre. There is also a size below which he should not go if he wants to make the most money for each thousand board feet of timber handled. These 2 minimum cutting limits for the 4 stands studied are given in table 12. Both these economic limits, of course, are affected by the products into which the timber is cut and the comparative production costs of the different companies, particularly the cost of permanent improvements in the woods. The smallest pine tree that paid its way, not including stumpage, Federal taxes, interest, or profit, was 10 inches in diameter; it was found at the operation in Texas. The reason for this low limit was that the company cut its small logs into timbers and dimension, for which there was a very good market close at hand, with the result that the 10-inch trees were worth about $4 more per thousand board feet than those at the study in southern Arkansas, where no timbers were cut. Cutting a high percentage of the small trees into timbers and dimension also reduced mill costs and in addition increased overrun, thereby reducing woods costs. In contrast with this was the operation in the mountains of western Arkansas, where a virgin shortleaf pine tree had to be 15 inches in diameter to pay its way. If stumpage, Federal taxes, and interest

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are added to the production cost these cutting limits will have to be raised from 2 to 4 inches.

TABLE 12.—*The smallest tree that paid its way and the minimum-diameter cutting limits that yielded the highest return per acre and per thousand board feet for the operations studied*

Class of timber	Average age of stand	Diameter breast high of the smallest tree that paid its way [1]	Minimum-diameter cutting limit that yielded the highest gross return	
			Per acre	Per thousand board feet, lumber tally
	Years	*Inches*	*Inches*	*Inches*
Second-growth, forest-grown shortleaf and loblolly pine in southern Arkansas	58	12	12	16
Second-growth old-field loblolly pine in northern Louisiana	42	16	15	15
Virgin-growth flatland shortleaf pine in eastern Texas	122	10	10	20
Virgin-growth mountain shortleaf pine and mixed oak in west-central Arkansas	144	15	14	19

[1] Excluding stumpage, Federal taxes, and interest.

The minimum-diameter cutting limit that yields the highest profit per acre is of greatest interest to the operator who does not care to log a second time and wants to cut the timber the first time so that he may make the most money. From this standpoint the minimum-diameter cutting limit ranges from 10 inches in virgin shortleaf pine, where a large percentage of the small trees was cut into timbers and dimension, to 14 inches in the virgin shortleaf-mixed oak type of stand in the mountains of western Arkansas, where practically no timbers were cut, the entire log going into lumber, and then again upward to 15 inches in the old-field stand of northern Louisiana. At the area in southern Arkansas, the owner would have made fully $2 more per acre if all trees below 12 inches in diameter had been left standing, and in addition about 1,400 board feet of young trees, per acre, would have remained on the ground to provide the nucleus for another cut and to supply seed.

If the mill has enough timber to keep it running satisfactorily the minimum-diameter limit that yields the highest profit for each thousand board feet handled should be considered. Of course this cutting limit, as usual, could not be followed strictly because it would not be either good forestry or good business to leave standing trees that were not growing at a fair rate or trees that were defective. The quality of the site would also affect the amount of timber that could be left and yet permit satisfactory reproduction. On poor sites the competition for moisture is more severe than on good, moist sites, and the stand left after cutting would therefore have to be lighter to permit reproduction to survive.

There is still another question, one for which the available data are insufficient, namely, the exact degree to which a stand must be opened up to get the most satisfactory increase in growth for the trees that are left standing. On the Ouachita National Forest, for example, timber-sale officers state that in general if a shortleaf pine tree is to increase its growth rate materially after selective cutting in the stand it must have around it an opening with a 25-foot radius.

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Selective cutting when properly executed will consider not only the size and the form and the thrift of the trees to be cut but also the species. On the Ouachita National Forest, in the shortleaf pine-mixed oak type of stand, the marking practice called for the removal of all merchantable hardwoods as a forest-improvement measure both because of their poor quality and because of a desire to favor the pine. Oftentimes shortleaf and loblolly pines are found growing together on old fields in which the fertility of the soil has been reduced by agricultural crops. On such land loblolly may not maintain its growth so well as shortleaf, and for that reason a selective cutting in such a stand might well favor shortleaf. On the other hand, on average sites loblolly grows more rapidly than shortleaf, when in mixture, although it cannot endure the competition that shortleaf can; this accounts for the fact that in mixed stands the loblolly trees are both larger and fewer than the shortleaf. Loblolly is also considered more windfirm than shortleaf, yet it does not cut into quality lumber so well. Considering all these things, probably the best way to mark such a stand for cutting would be to leave the thrifty trees of each species without exercising any conscious effort to favor either one.

PRACTICAL ASPECTS OF SELECTIVE LOGGING

If an operator leaves trees standing, good trees on which he could make some profit, with the idea of coming back later and cutting them after they have increased in volume and quality, he must have faith in the future of the lumber industry, confidence that the State will maintain equitable tax laws, assurance that fire will not ravage his holdings, and conviction that the method of cutting used is satisfactory. In addition, the mill cut and the productive capacity of his lands must be balanced reasonably well and, last but not least, his financial condition must be such as to permit the investment. Selective logging should not be entered into on the spur of the moment; it must have adequate plans carefully thought out. Although every business venture extending into the future for several decades requires long-time plans and contains an element of risk, the growing of timber should not be disparaged on this ground; it is little if any different from other long-term enterprises and, if the fifth largest of our national industries is even to hold its own, timberlands of good quality must be kept productive. Selective cutting offers one good way of doing this.

Fortunately for forestry practice, very little of the timber in the shortleaf-loblolly pine territory is logged with power skidders, so that in embarking on selective cutting no very radical changes in logging methods are ordinarily required. The lowered cut per acre under selective cutting and the absolute necessity of reducing to the very minimum the damage to the stand left on the ground, practically eliminate the power skidder. Animal or tractor logging, however, fits in well with selective cutting.

Existing information on logging selectively cut stands is not all satisfactory; it fails to point out the best methods. Intensive studies in this matter are needed. It is of course obvious that as the cut per acre is reduced, the track and camp costs rise, but many practical men think that logging methods can be changed and so improved as to partly offset this increase. The figures heretofore given show that certain costs, such as felling and milling, decrease under selective

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cutting, and even under present logging practice production costs do not increase until as much as 30 or 40 percent of the stand is left. But the lumber industry should not be satisfied with this situation, for further study of logging methods should develop practices that will decrease or at least hold constant the logging costs that increase under present practices. Good roads and the use of trucks make it possible to log stands selectively with but little if any additional cost, because expensive track and camp constuction is not required.

Because the trees left standing must be carefully protected from injury, some loggers insist that the costs of selective cutting are higher than those of clear cutting. Experience on national forests indicate that when once the men have become accustomed to working in selectively cut stands this objection to the practice is largely overcome.

Flexibility in the logging operation is also an advantage in handling selectively cut stands. The operator in many instances will wish to select his logging chances as well as the individual trees to be cut, the choice depending on market conditions and the relative maturity of the timber. The possibility of selecting for cutting only the timber that can be handled at a profit during depression periods is an excellent safeguard against financial difficulties at such times; it fits in nicely with a flexible logging set-up; and within limits is not inconsistent with good forestry practice.

One of the outstanding practical requirements of selective cutting is that enough trees of sufficient size and satisfactory thrift be left to seed in the openings made when the larger trees are cut and to yield another cut in a reasonably short time. Successful forestry practice depends in a large measure on keeping the land well stocked. In addition, the trees left standing should be capable of growing at an increased rate after their release, since otherwise one of the advantages of selective cutting is lost. To gain this objective care in selecting the trees to be left is necessary. The most accurate method of determining the rate of growth of a tree is to cut a small core out of it and measure the annual growth rings. An instrument known as an increment borer is best for this purpose. The general appearance of a tree is also a good indication of its thrift, especially to one intimately acquainted with the timber type. Rounded or pointed tops, dense crowns of a dark green color, and grayish bark are usually indications of a thrifty young pine tree and may be used as a guide by an experienced man.

Clear, wide, high-grade boards come only from large clear-boled trees (fig. 6). Hence in cutting selectively with the production of as much of this class of material as possible in mind, it is doubly important to select with extreme care the larger trees that are to be left so that the period when they will produce high-grade material may not be delayed too long.

The general quality of the succeeding cuts from an area can be greatly increased by removing poorly formed and defective trees from the stand. Such a practice also releases valuable space to young growth that should develop under good management into material of much higher quality than the trees it replaces.

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ADVANTAGES OF SELECTIVE LOGGING

Selective logging, in addition to being one of the best methods (*1*, *2*, *3*) of keeping southern pine lands fully productive, makes it

FIGURE 6.—The relation of clear boles and clear lumber: (A) Open stands of young, old-field southern yellow pine are often limby and consequently yield little clear lumber, whereas (B) virgin stands as well as (C) second-growth, forest-grown stands, in which the trees have shed their lower limbs early in life, have good, clear boles and produce a fair amount of the higher grades of lumber.

possible to remove a principal part of the value of the stand in the form of large trees and yet remove a small fraction of the total volume;

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that is, selective logging removes the greatest value with the least volume, because the large trees that are cut are worth more per thousand board feet than the small ones.

By careful cutting an even-aged stand may be converted into an all-aged stand in which the trees that are removed at each cutting should be of good quality unless wind damage or other accidental injury has occurred. Under such a plan, with a reasonable volume removed there would be little or no delay in getting reproduction started because in shortleaf and loblolly pine (*3*) some seed is borne nearly every year. A stand selectively cut over is much less likely to allow the inroads of undesirable species, such as scrub oak, or even another pine that in time would change the type, than is one cut clear or with only seed trees left. It is also possible to rid the stand of undesirable hardwoods that may already be present. Hardwoods of good quality, however, may be handled along with the pine and are of value in maintaining desirable soil conditions and in hastening the natural process of pruning of the major species in the stand. Soil-moisture conditions are better in selectively cut stands because of the protection from the sun and wind afforded by the trees left standing. This condition is more satisfactory for seed germination and probably reduces the mortality of seedlings as compared with the results on clear-cut lands having no overhead protection.

The fire hazard, as a rule, is less on selectively cut areas than on clear-cut lands because there is less slash, the humidity of the air is higher, and the wind velocity is lower (*9*). Furthermore, general conditions are less favorable for fire in a selectively cut area because in the spring the inflammable material on the ground, shaded by the trees, dries out more slowly and in the fall the ground growth stays green longer than on clear-cut areas. In addition, although selective cutting opens more territory to the fire hazards of lumbering operations than does clear cutting, for the same amount of timber, the presence of men on the ground and the fact that the trees left standing furnish are incentive for fire protection and care would appear to be sufficient to offset this seeming disadvantage.

Selective cutting makes possible an early second cut, a procedure that has many advantages. The sooner a return cut is made the less expense there will be in reclearing and resurfacing old rights of way for logging spurs. Although there are no definite figures available, experienced loggers estimate that regrading an old right of way costs only about half as much as grading a new route for the first time.

An early second cut may also be the means of extending the life of a mill, in a measure filling in the gap between the exhaustion of one crop of timber and the obtaining of another through regrowth. Timber, of course, is the first requirement of a mill, its raw material. The supply of raw material must be continuously adequate if the mill is to make money.

Selective logging as a means of perpetuating the forest and keeping lands productive can exercise a tremendous influence on business and social stabilization and development in many large forest areas of the South, and a controlling influence in not a few of them. Clear cutting without provision for regrowth makes the reverse true. All such accompaniments of clear cutting add to the cost of operation and many times reduce profits measurably. Forestry practice is not a cure for all the ills that beset the lumber industry, yet handling forest lands

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so that they will supply continuous crops of timber is one of the most important steps that can be taken in developing and stabilizing the lumber industry of the South.

The growth increment in selectively cut stands is of higher quality than in even-aged stands of the same volume. Figure 7, picturing the quality of the lumber found in typical virgin shortleaf pines of different sizes, shows especially the increase in B and better lumber with increase in diameter breast high. This, in turn, shows why wood laid on by large trees is worth more than an equal volume grown by small ones.

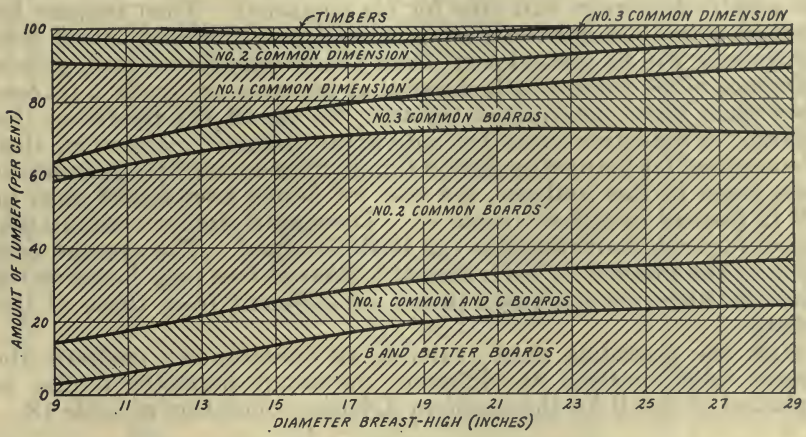

FIGURE 7.—Comparative amounts of the different grades of lumber obtained from virgin shortleaf pine of different diameters, in a typical stand; the percentages are plotted cumulatively.

Under a thorough selective logging plan a given area of land will produce timber more cheaply than under clear cutting and planting. Zeigler, Bond, and Spillers [7] compared two areas in Alabama on which it was planned to grow shortleaf and loblolly pine by selective cutting and by planting. Their computation shows that the actual cost of growing, or in other words the cost of the stumpage under selective cutting, was $1.18 less per thousand board feet international ¼-inch kerf log scale than under clear cutting and planting.

SUGGESTIONS FOR COMPUTING CUTTING LIMITS

Under ordinary conditions plans for handling southern pineland will vary from the simplest minimum-diameter cutting limit for the operator who wants to make the most money per acre and move on, to the extensive ideas of the large owner who has a heavy investment in plant and lands and desires to manage his holdings so that they will supply his sawmill with raw material continuously, and perhaps supply a pulp mill also. In any operation within this wide range the basic data on production costs and quality differences previously presented will be helpful in working out the proper cutting plan.

Since the study covers the four main classes of shortleaf-loblolly pine timber, an operator should be able to select from this bulletin an example that will closely approximate his own holdings. Having

[7] ZEIGLER, E. A., BOND, W. E., and SPILLERS, A. R. A FINANCIAL STUDY OF GROWING LOBLOLLY AND SHORTLEAF PINES IN THE FARM WOODLANDS IN LEE COUNTY, ALABAMA. South. Forest Expt. Sta. [Rpt.] 90 p., illus. 1930. [Unpublished.]

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done this he will wish to cruise a fair sample of his own woods, perhaps 40 sample acres or more, well distributed over his holdings, for the purpose of determining the volume distribution of the stand among the different diameter classes; that is, the percentage of the total volume that occurs in each size class of tree. Figures in this bulletin can then be applied to such a table for the purpose of working out minimum cutting limits.

In illustration, assume that the total unit production costs of table 7 for the southern Arkansas stand, when multiplied by the owner's volume distribution figures, give $19.50 per thousand board feet as the weighted-average unit cost for his operation. Then suppose his average actual production cost is $18.52 per thousand board feet. Subtracting $18.52 (actual cost) from $19.50 (calculated cost) gives a difference of 98 cents, which shows that his costs are really 5 percent lower than those determined through the use of the figures in this bulletin. Production costs for individual diameter classes can then be computed for his own operation simply by reducing by 5 percent the costs given in this bulletin; the cost for 9-inch trees would then be $27.42 instead of $28.86 (table 7). Through a similar computation figures for each diameter class can be determined. The average sales value of the lumber for each diameter class of tree may be corrected similarly when an operator's prices are different from those of this bulletin.

With the preceding data available an operator can compute the returns when cutting to different minimum diameter limits, as explained in detail for the southern Arkansas operation in table 13.

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TABLE 13.—*Gross return per thousand board feet, lumber tally, and per acre in cutting to different minimum-diameter limits, in a typical stand of second-growth, forest-grown mixed shortleaf and loblolly pine in southern Arkansas*

Diameter breast high	Volume per acre cut from the diameter class	Cost per thousand board feet, lumber tally, excluding spur cost [1]	Cost per acre, excluding spur cost	Sales value per thousand board feet, lumber tally	Sales value of lumber per acre	Diameter breast high for cutting	Total volume per acre removed at the minimum-diameter cutting limit	Cumulative cost per acre, excluding spur cost	Cost per thousand board feet, lumber tally, excluding spur cost	Spur cost per thousand board feet, lumber tally	Total cost per thousand board feet, lumber tally	Cumulative sales value per acre	Sales value per thousand board feet, lumber tally	Gross return per thousand board feet, lumber tally	Gross return per acre
1	2 [2]	3 [3]	4 [4]	5 [5]	6 [6]	7	8 [7]	9 [8]	10 [9]	11 [10]	12 [11]	13 [12]	14 [13]	15 [14]	16 [15]
	Bd. ft.	*Dollars*	*Dollars*	*Dollars*	*Dollars*		*Bd. ft.*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
8 inches	25	31.64	0.79	21.62	0.54	8 inches and up	12,636	244.48	19.35	1.37	20.72	314.39	24.88	4.16	52.57
9 inches	240	27.49	6.60	22.05	5.29	9 inches and up	12,611	243.69	19.32	1.37	20.69	313.85	24.89	4.20	52.97
10 inches	456	24.87	11.34	22.52	10.27	10 inches and up	12,371	237.09	19.16	1.40	20.56	308.56	24.94	4.38	54.18
11 inches	668	23.20	15.50	22.94	15.32	11 inches and up	11,915	225.75	18.95	1.45	20.40	298.29	25.03	4.63	55.17
12 inches	949	21.95	20.83	23.35	22.16	12 inches and up	11,247	210.25	18.69	1.54	20.23	282.97	25.16	4.93	55.45
13 inches	1,340	20.82	27.90	23.62	31.65	13 inches and up	10,298	189.42	18.39	1.68	20.07	260.81	25.33	5.26	54.17
14 inches	1,515	19.88	30.12	24.12	36.54	14 inches and up	8,958	161.52	18.03	1.93	19.96	229.16	25.58	5.62	50.34
15 inches	1,517	19.09	28.96	24.69	37.45	15 inches and up	7,443	131.40	17.65	2.33	19.98	192.62	25.88	5.90	43.91
16 inches	1,428	18.42	26.30	25.22	36.01	16 inches and up	5,926	102.44	17.29	2.92	20.21	155.17	26.18	5.97	35.38
17 inches	1,224	17.79	21.77	25.64	31.38	17 inches and up	4,498	76.14	16.93	3.85	20.78	119.16	26.49	5.71	25.68
18 inches	986	17.30	17.06	26.06	25.70	18 inches and up	3,274	54.37	16.61	5.29	21.90	87.78	26.81	4.91	16.08
19 inches	758	16.85	12.77	26.42	20.03	19 inches and up	2,288	37.31	16.31	7.57	23.88	62.08	27.13	3.25	7.44
20 inches	569	16.44	9.35	26.89	15.30	20 inches and up	1,530	24.54	16.04	11.31	27.35	42.05	27.48	.13	.20
21 inches	392	16.12	6.32	27.35	10.72	21 inches and up	961	15.19				26.75			
22 inches	266	15.83	4.21	27.79	7.39	22 inches and up	569	8.87				16.03			
23 inches	164	15.57	2.55	28.24	4.63	23 inches and up	303	4.66				8.64			
24 inches	88	15.31	1.35	28.66	2.52	24 inches and up	139	2.11				4.01			
25 inches	38	15.08	.57	29.10	1.11	25 inches and up	51	.76				1.49			
26 inches	13	14.92	.19	29.44	.38	26 inches and up	13	.19				.38			
Total	12,636														

[1] Excluding stumpage, Federal taxes, and interest.

[2] The volume of timber, per acre, in the corresponding diameter class of column 1, expressed in board feet, lumber tally.

[3] The respective totals of table 4 minus $1.37, the cost of spur tracks, camps, and roads, which varies with the amount of timber cut per acre.

[4] Column 2 figures multiplied by the corresponding figures of column 3 and divided by 1,000.

[5] Values from table 6.

[6] Column 2 figures multiplied by the corresponding figures of column 5 and divided by 1,000.

[7] The cumulative totals of column 2 figures, starting with the largest diameter class and cutting all trees of the diameter of the corresponding column 1 figure and larger, expressed in board feet, lumber tally.

[8] The cumulative totals of column 4 figures, starting with the largest diameter class and going down to the limit of the corresponding column 1 figure.

[9] Column 9 figures divided by the corresponding figures of column 8, which were first divided by 1,000.

[10] The cost of spur tracks and so forth ($17.31 per acre) divided in turn by column 8 values, which were first divided by 1,000.

[11] Column 10 figures plus the corresponding figures of column 11.

[12] The cumulative totals of column 6 figures, starting with the largest diameter class.

[13] Column 13 figures divided by the corresponding figures of column 8, which were first divided by 1,000.

[14] Column 14 figures minus the corresponding figures of column 12.

[15] Column 15 figures multiplied by the corresponding figures of column 8, which were first divided by 1,000.

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SUMMARY

The stabilization and further development of the timber industry in the South depends very largely upon keeping southern forest lands continuously productive. Selective cutting seems to be an excellent method of accomplishing this on most shortleaf and loblolly pine areas. Such a cutting practice also fits in satisfactorily with permanent or sustained-yield operations.

With extension of good roads and improvement in logging methods, selective-cutting plans can be adapted to log a stand to the best advantage, whether economic conditions are good or bad, and yet preserve to a reasonable degree the silvicultural aims of proper management. Under such a plan areas as well as individual trees may be selected for cutting.

The economic justification for selective cutting lies in the basic fact that production costs are lower for large trees than for small trees, and in addition, because of higher grades and greater widths, the lumber from large trees is worth more per thousand feet, board measure, than is that from small trees. On the average it costs twice as much to produce 1,000 board feet of lumber from shortleaf and loblolly pine trees 8 inches in diameter as to produce the same quantity of lumber from similar trees 24 inches in diameter; further, the lumber from the small trees is worth only about three fourths as much as that from the large trees. For every operation there is a diameter limit below which trees do not pay their way in lumber production. This limit differs with types of timber and should be determined in each instance no matter what the ultimate objective of the operation may be, for it has a bearing on both profits and cutting practice.

Under sustained-yield management in which the stand is handled from decade to decade, every effort should be made to grow wood of quality as well as quantity. Proper stocking, hardwoods in mixture with the pine, and even pruning done under favorable conditions are some of the important measures that rid the trees of their lower limbs so that they may lay on clear wood at an early age. Further, age also has an effect; in general, size for size, the older trees contain lumber of higher quality than that in the younger ones. When once selective cutting is in operation, trees need not be cut while still young, as is desirable in clear-cutting operations, but may be cut at almost any age as long as the distribution of size classes is such that enough timber can be obtained at each cutting cycle to make logging practicable.

Since it is fairly certain that increased profits from lumber production, over a long period in the future, will result more from closer utilization and lowered production costs than from extremely high lumber prices, selective cutting is especially important because of its direct bearing on costs, returns, and utilization. Ordinary computation shows that permanent or sustained-yield operation will be more profitable than period operation. In addition, logs from small unprofitable, unthrifty trees are kept from clogging the mills.

The fire hazard is less in selectively cut stands than on clear-cut areas.

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LITERATURE CITED

(1) Ashe, W. W.
1915. LOBLOLLY OR NORTH CAROLINA PINE. N. C. Geol. and Econ. Survey Bul. 24, 176 p., illus.

(2) ———.
1926. PROFIT IN CUTTING TIMBER FOR A PERMANENT YIELD. Lumber World Rev. 50: 25–26.

(3) Forbes, R. D.
1930. TIMBER GROWING AND LOGGING AND TURPENTINING PRACTICES IN THE SOUTHERN PINE REGION: MEASURES NECESSARY TO KEEP FOREST LAND PRODUCTIVE AND TO PRODUCE FULL TIMBER CROPS. U.S. Dept. Agr. Tech. Bul. 204, 115 p., illus.

(4) ——— and Bruce, D.
1930. RATE OF GROWTH OF SECOND-GROWTH SOUTHERN PINE IN FULL STANDS. U.S. Dept. Agr. Circ. 124, 77 p., illus.

(5) Hallauer, F. J.
1930. WILL SUSTAINED YIELD IN LUMBER OPERATION COME THROUGH REGULATION OR THROUGH COMPETITION? Jour. Forestry 28: 942–951.

(6) Sudworth, G. B.
1927. CHECK LIST OF THE FOREST TREES OF THE UNITED STATES, THEIR NAMES AND RANGES. U.S. Dept. Agr. Misc. Circ. 92, 295 p.

(7) Teesdale, L. V.
1930. THE KILN DRYING OF SOUTHERN YELLOW PINE LUMBER. U.S. Dept. Agr. Tech. Bul. 165, 67 p., illus.

(8) United States Department of Agriculture, Forest Service.
1929. VOLUME, YIELD, AND STAND TABLES FOR SECOND-GROWTH SOUTHERN PINES. U.S. Dept. Agr. Misc. Pub. 50, 202 p., illus.

(9) Zon, R., and Garver, R. D.
1930. SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE STATES. U.S. Dept. Agr. Tech. Bul. 164, 47 p., illus.

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